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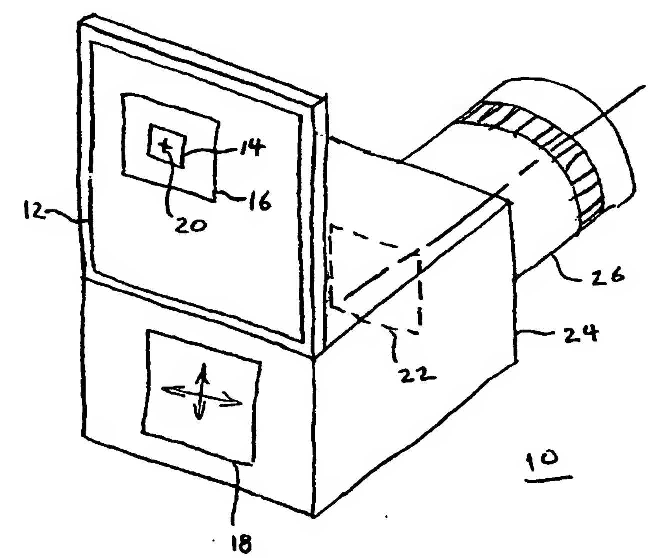
(54) Title: TARGETABLE AUTOFOCUS SYSTEM



(57) Abstract: A digital camera comprises a light-tight housing. At least one solid-state array image sensor is disposed in the housing. A lens is optically coupled to the solid-state array image sensor through the housing. A viewing screen is coupled to the solid-state array image sensor for viewing an image sensed by the solid-state array image sensor. A user-operated pointing device is used to select a point anywhere on the image. Circuitry associated with the solid state array image sensor is responsive to the pointing device for presenting on the viewing screen an area associated with the point on the image, the area being magnified and having higher resolution with respect to the remainder of the image.

WO 00/72584 A1

TARGETABLE AUTOFOCUS SYSTEM

1. Field of the Invention

The present invention relates to digital imaging devices and to digital cameras. More particularly, the present invention relates to a targetable autofocus system and to a digital camera employing a targetable autofocus system.

2. The Prior Art

Autofocus systems are known in the prior art, particularly as represented in consumer "point and shoot" cameras, and also in professional level single-lens reflex cameras. These systems operate by splitting the image in a small active area in the center of the field of view into two sub-images. These two sub-images are then passed through separate optical paths and compared to produce an electrical error signal that is an odd function of the defocus distance, as is well known by those of ordinary skill in the art. This error signal is used to operate the focus motor of the lens, thereby bringing the sub-image into focus. The direction that the focus motor is to be driven is known from the sign of the odd error signal.

Looking through the view finder of such a camera, the photographer aims the box delineating the focus area at the part of the image that he or she desires to be in focus, depresses the shutter release button half way, moves the camera to achieve the desired framing for the shot, and then depresses the shutter release button all the way, thereby actually exposing the image. Some of the more advanced cameras have several sub-image areas that are switched between by the camera using some algorithm. Some of the Canon cameras even attempt to track the eye position of the photographer to determine which of the predetermined sub-images to use for a particular exposure.

Digital cameras have simply copied this style of auto-focus system, providing no advantage over their film counterpart. It is an object of the present invention to provide an auto-focus system for a digital camera that uses the signals from the same digital image sensor that is used to capture the image to operate the focus motor, without the requirement of a separate optical system or sensor. It is a second object of the present invention to provide an auto-focus system for a digital camera that operates on a sub-image area selectable by the user rather than fixed by the manufacturer.

BRIEF DESCRIPTION OF THE INVENTION

BRIEF DESCRIPTION OF THE DRAWING FIGURES

FIG. 1 is a schematic diagram of a front view of a viewfinder display for an electronic camera.

FIG. 2 is an image showing the appearance of the display employing the present invention.

FIG. 3 is a plot of focus metric as a function of lens focus setting.

FIG. 4 is a block diagram of a circuit for computing individual data points of the focus metric shown in FIG. 3.

FIG. 5 is a flow diagram is used to illustrate a method for performing autofocus according to the present invention.

FIG. 6 is a flow diagram of a process that may be used for calculating a new focus metric for use in the method of FIG. 5.

FIG. 7 is a flow diagram illustrating a process for setting an initial focus wheel increment for use in the method of FIG. 5.

FIG. 8 is a flow diagram illustrating a method for computing a fit to a parabolic error curve, and focusing at the estimated best position.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Persons of ordinary skill in the art will realize that the following description of the present invention is illustrative only and not in any way limiting. Other embodiments of the invention will readily suggest themselves to such skilled persons having the benefit of this disclosure.

The present invention can be better understood with reference to FIG. 1, which shows, in schematic form, a view of a viewfinder display for an electronic camera 10. The main window 12 is used to display the entire image that is within the field of the electronic imaging array used to capture the image. Persons of ordinary skill in the art will understand that any high-quality imaging array will have much higher resolution than can be fully displayed on an electronic display small enough to fit on a portable camera, and hence only a small fraction of the actual pixels in the sensor array are addressed in order to produce the video stream used to form the image displayed in window 12. For example, a high-quality imaging system can be formed using three 2,000 by 2,000 pixel sensor chips attached to a color-separating prism as described in co-pending application serial No. 09/302,565, filed April 30, 1999, entitled "COLOR SEPARATION PRISMS HAVING SOLID-STATE IMAGERS MOUNTED THEREON AND CAMERA EMPLOYING SAME" Attorney's Docket No. FOV-031, assigned to the same assignee as the present invention and expressly incorporated by reference herein.

A typical liquid-crystal viewfinder display has 512 by 512 pixels. To display a video image from the sensor array on the viewfinder screen, every fourth row of the sensor array is addressed, and every fourth pixel is outputted from each addressed row. In the present example where every fourth pixel is used, a 500 by 500 pixel displayed image is created, containing one 16th of the total number of pixels of the full 2,000 by 2,000 sensor array. This subsampling of the sensor array may be accomplished by addressing circuitry integrated on the sensor chip, as disclosed, for example, in co-pending application serial No. 09/120,491, filed July 21, 1998, entitled "IMAGE SCANNING CIRCUITRY WITH ROW AND COLUMN ADDRESSING FOR USE IN ELECTRONIC CAMERAS" and assigned to the same assignee as the present invention. This prior application is expressly incorporated by reference herein. The advantage of creating the viewfinder image by on-chip subsampling of the sensor array is that the number of pixels to be read off the chip is reduced by a large factor (16 in the example just cited), thereby allowing a faster frame rate viewfinder to be implemented within the bandwidth limit of the readout system.

Referring again to FIG. 1, a selectable sub-area 14 of the image in the main window 12 is defined by the user by, for example, using a pointing device 18 like a touchpad,

joystick, or the like to move and position a cursor-like target, cross-hairs, or other indicator (indicated at reference numeral 20) centered therein at a region of interest in an image. Sub-area 14 is selected by the user as an area of the image that is of particular interest, such as the eye of a person of which a photograph is to be taken. Because each photographic composition is unique, it is important that the region of interest be movable by the photographer. The present invention provides this feature, which is not available in the prior art.

In operation, the sub-area 14 is scanned out at full resolution, also using the addressing circuitry integrated on the sensor chip, as disclosed in co-pending application serial No. 09/120,491. The pointing device 18 is centered by the user on a point of interest anywhere in the image. As will be readily understood by persons of ordinary skill in the art having the benefit of this disclosure and that of co-pending application serial No. 120,491, the starting row and column addresses for sub-area 14 are easily derived from the row and column addresses of the position of the pointing device 14 defining the center of sub-area 14. The starting row address of the sub-area 14 is derived by subtracting half of the length (in rows) of the sub-area 14 from the row address of the position of the pointing device. The starting column address of the sub-area 14 is derived by subtracting half of the width (in columns) of the sub-area 14 from the column address of the position of the pointing device.

The result is a full-resolution image that, when displayed at viewfinder screen resolution, is larger than area 14. Using the numbers from the example system disclosed herein, the area required to display sub-area 14 on the screen at full resolution would be 4 times larger in each dimension, or 16 times larger in area, than the area defined as sub-area 14.

According to a presently preferred embodiment of the invention, the full-resolution version of area 14 is displayed as magnified area 16, centered on area 14, and replaces the corresponding image region on the original display. The visual impression created by this superposition is that of a magnifying glass or "loupe", expanding the portion of the image of sub-area 14 beneath it. The appearance of the display according to the present invention is shown on the image in FIG. 2. Magnification techniques have been used for material such as text or images stored in computer memory, but have not been used for magnifying a user-

selectable sub-area of the live viewfinder image in a portable electronic camera as in the present invention. The ability to scan the high-resolution image sensors in two different modes interleaved in time is crucial to achieving the magnified sub-image without compromising performance. In the presently preferred embodiment of the present invention, this interleaving is achieved by storing the start and stop addresses and the addressing increment for each of the modes in control registers on the chip, as disclosed in co-pending application serial No. 120,491, filed July 2, 1998, and toggling between them to retrieve the data in area 12 and sub-area 16.

The viewfinder may be mounted on camera 10 at a convenient location. As will be appreciated by persons of ordinary skill in the art, camera 10 focuses an image onto at least one imager array 22 located in light-tight enclosure 24 via lens 26. Lens 26 is a variable focus lens and is equipped with a focus motor to move the lens elements as is known in the art.

A second aspect of the present invention is to utilize the data displayed in sub-area 16 to drive the focus motor of the camera lens 26, thereby achieving an autofocus capability specifically within the region of interest selected by the photographer. Because sub-area 16 of the image has a small amount of data compared with the entire image in main window 12, it can be refreshed at a much higher rate.

A high-resolution electronic imaging system located in the image plane of the camera lens does not provide an odd-error signal as required by prior-art camera auto-focus systems. There has been work on using even-error metrics of focus quality from imaging arrays to operate a focus system, as described, for example, in T. Delbruck, ``A chip that focuses an image on itself'', in Analog VLSI implementation of neural systems, C. Mead and M. Ismail, Eds., chapter 7, pp. 171-188. Kluwer Academic Publishers, Boston, 1989, Proceedings of a workshop on Analog Integrated Neural Systems. According to the present invention, an even-error metric of image quality is developed from the image itself, for example by taking the sum of the squares of first-difference of adjacent pixels over the area. A plot of this kind of focus metric as a function of lens focus setting is shown in FIG. 3. One of the individual data points for the focus metric is indicated at reference numeral 28.

According to the present invention as illustrated in FIG. 3, the measured function is fitted to a parabola, and the lens focus setting returned to the position of computed maximum (best focus). Although this kind of computation has been performed before, it has not been possible to accomplish in the context of a portable, high-resolution camera because it requires many images to be scanned out, each at a different lens focus setting. The time required to scan out a high-resolution image is of the order of one second, and thus scanning out many images could not result in a real-time auto-focus system. However, scanning out user-selected sub-image 16 at high resolution according to the present invention can be done in a small fraction of a second. The plurality of sub-images, each at a different lens focus setting, that is required for computing the point of best focus can be done within a second. Thus the present invention makes possible a real-time autofocus system that optimizes the focus in the area of the image selected by the user.

Referring now to FIG. 4, a block diagram is presented of a circuit 30 for performing an illustrative computation that determines individual data points of the focus metric shown in FIG. 3. The circuit 30 is driven by three lines. First, the pixel data stream is presented on line 32. The pixel clock is presented on pixel clock line 34. A New Image signal is presented on New Image line 36. A pixel0 register 38 is driven by the pixel data stream on line 32 and the pixel clock on line 34. Pixel0 register 38 is first cleared by New Image signal on line 36. The next clock pulse on pixel clock line 34 clocks the value of the current pixel (pixel0) into pixel0 register 38.

The second clock pulse on pixel clock line 34 clocks the value of the new current pixel (pixel0) into pixel0 register 38 and also clocks the most recent old current pixel (pixel-1) into pixel-1 register 40. Pixel-1 register 40 has also been cleared by New Image signal on line 36. The pixel-1 output of pixel-1 register 40 is multiplied by (-1) in multiplier 42 to change its sign and is then subtracted from the value of the current pixel0 in adder 44. The subtraction result is squared in unit 46.

The output of unit 46 is added to the output of focus-metric register 48 in adder 50. Persons of ordinary skill in the art will appreciate that focus-metric register 48 has also been cleared by the New Image signal on line 36. Therefore, focus-metric register 48 will contain

the value zero after the first pixel clock pulse following assertion of the New Image signal on line 36. It will contain a value equal to the square of the value in pixel0 register 38 after the second pixel clock pulse following assertion of the New Image signal on line 36. It will contain a value equal to the sum of the squares of the first two pixel values only after the third pixel clock pulse following assertion of the New Image signal on line 36. After all of the pixel values for a sub-image have been clocked in, the output of focus-metric register 48 represents the sharpness of the sub-image. After the value has been read by some other register, the New Image signal is asserted on line 36 to reset all of the registers 38, 40 and 48 in circuit 30 and the next sub-image may be read into circuit 30. Circuit 30 assumes that each pixel value clocked in by the pixel clock is from a pixel adjacent to the previous pixel value clocked in and should not perform calculations on non-adjacent pixels, i.e., the last pixel on a line and the first pixel on the next line.

Persons of ordinary skill in the art will appreciate that circuit 30 can run in either of the horizontal and vertical lines of the sub-image, or that two such circuits 30 may be employed, one each on selected lines in the horizontal and vertical directions. Such skilled persons will also appreciate that the algorithm implemented by circuit 30 is not the only means for determining the focus of an image based upon pixel values. Another embodiment could filter the sub-image more through the use of an edge detect algorithm. Only pixels near the most defined edge could be run through such a system.

Referring now to FIG. 5, a flow diagram is used to describe an illustrative method for performing autofocus according to the present invention. The method of FIG. 5 searches for maximum image sharpness by obtaining focus metric values and moving the camera focus mechanism (referred to herein as the "focus wheel") to change lens focus based upon the three previous focus metric values. The system of FIG. 5 always tries to move the lens to achieve higher focus metric values based upon the focus metric history.

In the method illustrated in FIG. 5, the focus wheel increment value (FW) controlling how much the focus mechanism of the lens will be changed is initially set to zero at step 60. A first focus metric FM0 is then calculated (using, for example, circuit 30 of FIG. 4) at step 62. At step 64, the initial focus wheel increment value FW is set depending on whether or

not the focus metric FM0 is greater than a sharpness threshold. The FW increment set in step 64 is explained in greater detail in FIG. 7.

Next, at step 66, a new focus metric FM0 is calculated by circuit 30 using the focus wheel increment value FW. At step 68, a new focus metric FM0 is again calculated by circuit 30 using the current focus wheel increment value FW. At step 70, the new focus metric calculated at step 68 is compared to the most recent focus metric FM1 (from step 66) and the next most recent focus metric FM2 (from step 62) to test whether the condition $FM0 \geq FM1 \geq FM2$ is true. Step 66 was repeated at step 68 so that there are non-zero values for FM1 and FM2 the first time that the test in step 70 is performed. If the condition $FM0 \geq FM1 \geq FM2$ is true, then the current focus setting resulting in focus metric FM0 is at least as good as the most recent focus setting that resulted in focus metric FM1 and the most recent focus setting is at least as good as the next-most-recent focus setting that resulted in focus metric FM2. This indicates that the focus wheel FW is incrementing in a direction towards optimum focus. Step 72 is then performed to maintain the focus wheel increment at its current value FW.

If $FM0 \geq FM1 \geq FM2$ is not true at step 70, the new focus metric calculated at step 68 is compared to the most recent focus metric FM1 and the next-most-recent focus metric FM2 at step 74 to test whether the condition $FM0 < FM1 \geq FM2$ is true. If the condition $FM0 < FM1 \geq FM2$ is true, then the current focus setting is worse than the most recent focus setting that resulted in focus metric FM1 and the most recent focus setting that resulted in focus metric FM1 was not worse than the next-previous focus setting that resulted in focus metric FM2. This means that the current focus setting FM0 has moved past the optimum focus setting. In this case, step 76 is then performed to set the focus wheel increment value FW to a new value equal to -FW/2 in order to reverse the focus wheel direction back towards the optimum focus point. The magnitude of the increment is set to an amount equal to half that of the previous increment in order to avoid overshooting the optimum focus point

If $FM0 < FM1 \geq FM2$ is not true, the new focus metric calculated at step 68 is compared to the most recent focus metric FM1 and the next-most-recent focus metric FM2 at step 78 to test whether the condition $FM0 > FM1 < FM2$ is true. If the condition $FM0 > FM1 < FM2$ is true,

then the current focus setting is better than the previous focus setting that resulted in focus metric FM1 but the most recent focus setting that resulted in focus metric FM1 is not as good as the next-most-recent focus setting that resulted in focus metric FM2. This condition is typically true when a new focus metric has been calculated using the focus wheel increment value FW = -FW/2 following the condition FM0<FM1>FM2 and the current focus setting that resulted in focus metric FM0 has moved back towards the optimum focus setting. In this case, step 80 is then performed to set the focus wheel increment value FW to the value FW/2 to increment the focus wheel further towards the optimum point by half the previous increment to avoid overshoot.

If FM0>FM1<FM2 is not true, then the current focus setting is not as good as the most recent focus setting that resulted in the focus metric FM1 and the most recent focus setting that resulted in the focus metric FM1 was not as good as the next -most-recent focus setting that resulted in the focus metric FM2. This means that the initial focus setting FM2 was past the optimum focus setting and the focus settings FM1 and FM0 continue to move away from the optimum focus setting. In this case, step 82 is then performed to set the focus wheel increment FW to the value -2FW to reverse the focus wheel direction back towards the optimum point by a larger increment. This will reverse the sign (direction of travel) of the focus wheel increment value FW and bring the focus setting back to the setting that resulted in the focus metric FM2. As will be understood from an examination of FIG. 6, the focus wheel increment value will increment in a direction towards optimum focus the next time a focus metric is calculated.

After performance of any of steps 72, 76, 80, or 82, step 84 is performed to test whether the current focus wheel increment value FW is less than 1. If FW<1, then the optical system is close enough to an in-focus condition and the process stops. If not, the process returns to step 68 to calculate a new focus metric FM0.

Referring now to FIG. 6, a flow diagram is used to illustrate a method for calculating a new focus metric for use in the method of FIG. 5. First, at step 90, the focus wheel is moved by the increment FW. Next, at step 92, a new image is captured by the imager using the new focus setting. In steps 94, 96, and 98, respectively, the old FM2 value is replaced by

the old FM1 value, the old FM1 value is replaced by the old FM0 value, and the old FM0 value is replaced by the FM value calculated for the newly-acquired image. As previously noted with respect to steps 66 and 68 of FIG. 5, these two steps are performed in order to provide initial non-zero values for FM1 and FM2.

Referring now to FIG. 7, an illustrative method is shown for selecting an initial focus wheel increment value FW to use in the process of FIG. 5. First, at step 100, FW is set equal to 64. Then at step 102, a determination is made whether the first FM0 calculated at step 62 is greater than a sharpness threshold. If not, the FW initialization ends with the value FW set to 64. If, however, the sharpness of the image FM0 was greater than the threshold, step 104 is performed to set the value FW to 2. Performance of this process strikes a balance between taking too much time to focus if the initial lens setting was significantly out of focus and using too large an FW increment and overshooting the optimal focus setting if the initial lens setting was close to optimum focus. By using the values 64 and 2, both of which are powers of 2, repeated performances of combinations of steps 76 and 80 will eventually reduce the value of FW to 0.5 to make the FW<1 condition of step 84 true to end the focus search algorithm of FIG. 5.

The method described in FIG. 5 is one of many possible methods of converging on a focus setting near the optimum. Ideally, it runs to completion, and stops after reducing the focus wheel increment (FW) to less than the minimum resolvable step of the lens motor (less than 1 in FIG. 5). If, however, the measurements of the focus metric (FM) are subject to noise, as would typically be the case, or if the subject is constantly in motion while running this method, then it is possible that the FW value will be successively halved and doubled many times as the method attempts to track the point of best focus. In this case, the method may not stop, or may not converge soon enough before the photographer snaps a picture. For such cases, it would be advantageous to fit a parabolic error curve to the recent FM values in order to compute a final FW increment that will drive the focus motor to an estimated best setting.

Whether the method of FIG. 5 is used, or some other method of sampling possible focus positions is used, it is therefore useful to be able to compute a final increment FW to drive the focus from its current setting to an estimated best focus setting.

Referring now to FIG. 8, a flow diagram illustrates a method for computing a fit to a parabolic error curve, and focusing at the estimated best position. In a first step 110 FP and FW are set to zero. FP is a focus position value and FW is the focus wheel increment value. At step 112, the lens focus wheel is moved by an amount FW and the position FP is updated to reflect the new position by setting FP = FP + FW. At step 114, the focus metric FM is measured. Next, at step 116, the averages of the quantities FP, FP2, FP^3, FP^4, FM, FM*FP, and $FM*FP^2$ are calculated. At step 118, it is determined whether all data has been taken. If not, at step 120 a new FW is chosen. The steps "choose Next FW" and "done?" may be defined to correspond to the steps in the method of FIG. 5 or as like steps in some other focus tracking method. For example, the "done?" test may be answered by user input, such as letting go of an auto-focus button or pressing a shutter release, or it may be answered by the convergence of a tracking method such as that described with reference to FIG. 5.

If the decision in the "done?" step 120 is yes, the method proceeds to determine an estimate of a best focus position by fitting a parabolic error function to the measurements from the settings. Many methods of parameter estimation are known; for simplicity, the well-known method of least-squares curve fitting to find a parabola (a quadratic, the simplest error function that has even symmetry about its optimum) that best fits the last N data values is used, where N is a chosen number of points, typically 5 to 10. In order to compute the fit of the parabola, the focus positions, which are not explicit in the method of FIG. 5, need to be obtained. To do so, either the absolute positions can be read from an encoder attached to the lens motor, or if such a device is not available, the method can simply start with an arbitrary position of zero and accumulate the increments FW to keep track of relative focus position FP, as shown in the method of FIG. 8.

As is well known in the art, the computation of the best fit to a quadratic error function can be done incrementally, since it depends only on average values of the independent variable FP, the dependent variable FM, and products and powers thereof

(means of FP, FP^2, FP^3, FP^4, FM, FM*FP, $FM*FP^2$). These averages can be computed as running averages of N points, or as exponentially weighted averages of points. Therefore, a focus-tracking method can stop and compute a final step FW at any time with little work.

According to the embodiment of the method shown in FIG. 8, a set of focus position (FP) values and focus metric (FM) values is used in steps 122 124, and 126 to compute the coefficients (A2, A1, and A0) of a best fitting quadratic function:

$$FM(FP) \sim= A2*FP^2 + A1*FP + A0$$

Equivalently, a parabola may be parameterized in terms of its center:

$$FM(FP) \sim= A2*(FP - FC)^2 + B0$$

where the parameter FC represents the focus-center or peak of the parabola in the focus-position dimension, and is given in step 128 by solving for the point where the first parameterization has zero slope:

$$FC = -A1/(2*A2)$$

The parameters A0 and B0 are not relevant to locating the best focus position but it is easiest to include them in the matrix solution to the least squares problem.

A further potential problem, in the case of a noisy focus metric, or in the case where there is little structure in the subject to focus upon, or in the case where the search has started near the optimum and moved only in very small increments, is that the estimated parablic error function could be nearly flat across the region sampled, or even inverted, such that the position of the best focus could be severely mis-estimated. A solution to this problem is to do a constrained least-squares fit in which the curvature parameter A2 is constrained to be more negative than (less than) some negative limiting value Amax, which will force the parabola to have a narrow enough peak and the estimated center value FC to be within or near the sampled positions FP even when there is little or no information in the FM data. If

Fig. 8, a fit to best values of A1 and A0 is computed with A2 fixed at Amax if the first computed value of A2 is not sufficiently negative.

Once the value of FC is determined in step 128, the lens can be returned to the position of best focus by setting FW = FC - FP as also shown at step 128 , where FP is the most recent focus position, and then incrementing the focus motor position by this final increment FW in step 130.

While embodiments and applications of this invention have been shown and described, it would be apparent to those skilled in the art that many more modifications than mentioned above are possible without departing from the inventive concepts herein. The invention, therefore, is not to be restricted except in the spirit of the appended claims.

What is claimed is:

1. A digital camera comprising:

a light-tight housing;

at least one solid-state array image sensor disposed in said housing;

an adjustable-focus lens having a focussing mechanism, said lens optically coupled to said solid-state array image sensor through said housing;

a viewing screen coupled to said solid-state array image sensor for viewing an image sensed by said solid-state array image sensor;

a user-operated pointing device that selects a point anywhere on said image;

circuitry associated with said solid-state array image sensor and responsive to said pointing device for presenting on said viewing screen a group of pixels representing an area associated with said point on said image, said area being magnified and having higher resolution with respect to the remainder of said image.

2. The digital camera of claim 1, further including:

circuitry for processing pixels representing said area associated with said point on said image to derive focus data; and

focussing means, coupled to said circuitry, for driving said focussing mechanism in response to said focus data from said circuitry such that said image is focussed on said imaging array within a selected tolerance.

3. The digital camera of claim 2 wherein said focus data defines a focus parabola and wherein said selected tolerance is a focus-center peak of said focus parabola.

4. In a digital camera having a light-tight housing, at least one solid-state array image sensor disposed in the housing, an adjustable-focus lens having a focussing mechanism, the lens being optically coupled to the solid-state array image sensor through the housing, a viewing screen coupled to the solid-state array image sensor for viewing an image sensed by the solid-state array image sensor, and a user-operated poining device that selects a focus point on said viewing screen, a method for focussing an image presented on the viewing screen comprising:

directing an image from the variable-focus lens onto said at least one solid-state array image sensor;

displaying said image on the viewing screen;

sensing an output signal from the user-operated pointing device identifying a point on said viewing screen;

defining an area associated with said point on said viewing screen;

reading a group of pixels from the at least one solid-state array image sensor that represent a magnified and higher-resolution view of a portion of said image associated with said point; and

displaying said group of pixels in said focus area on said viewing screen.

5. The method of claim 4 further including performing an autofocus operation on said group of pixels that adjusts the sharpness of said image from said variable-focus lens onto said at least one solid-state array image sensor.

6. The method of claim 5 wherein performing the autofocus operation comprises:

processing said group of pixels representing said area associated with said point on said image to derive focus data; and

driving the focussing mechanism of the lens in response to said focus data such that said image is focussed on said imaging array within a selected tolerance.

7. The method of claim 6 wherein processing said focus data comprises processing said focus data to define a focus parabola and wherein said selected tolerance is a focus-center peak of said focus parabola.

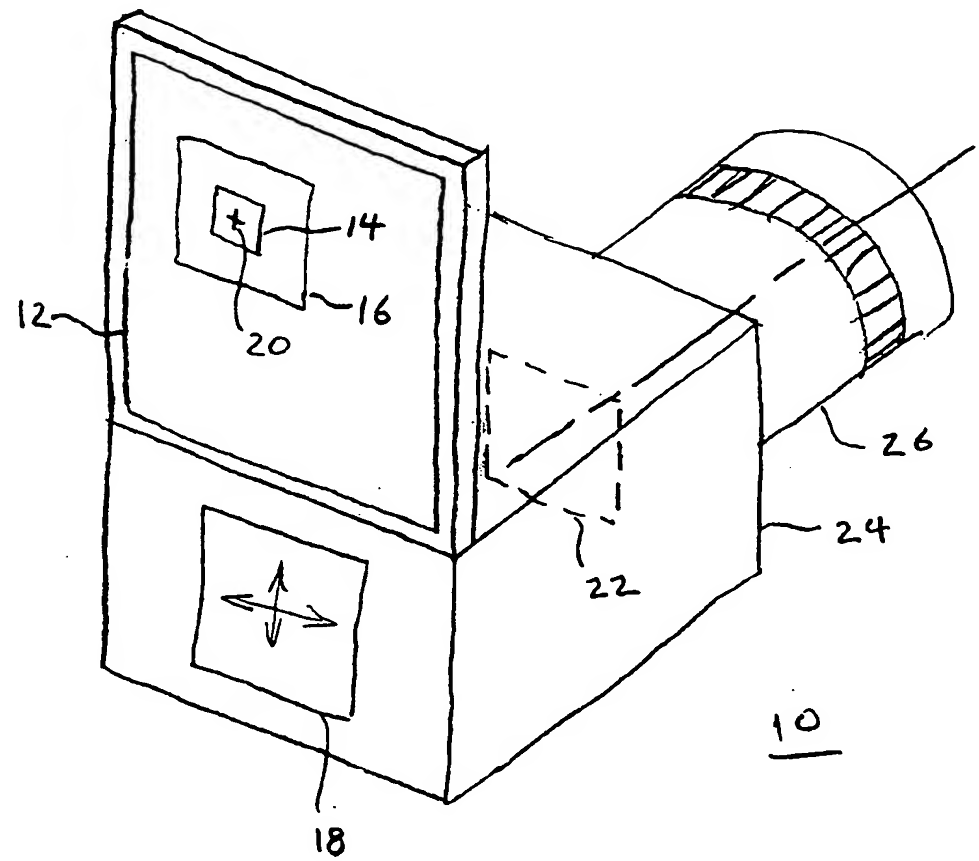


FIG. 1


Image1284.fov

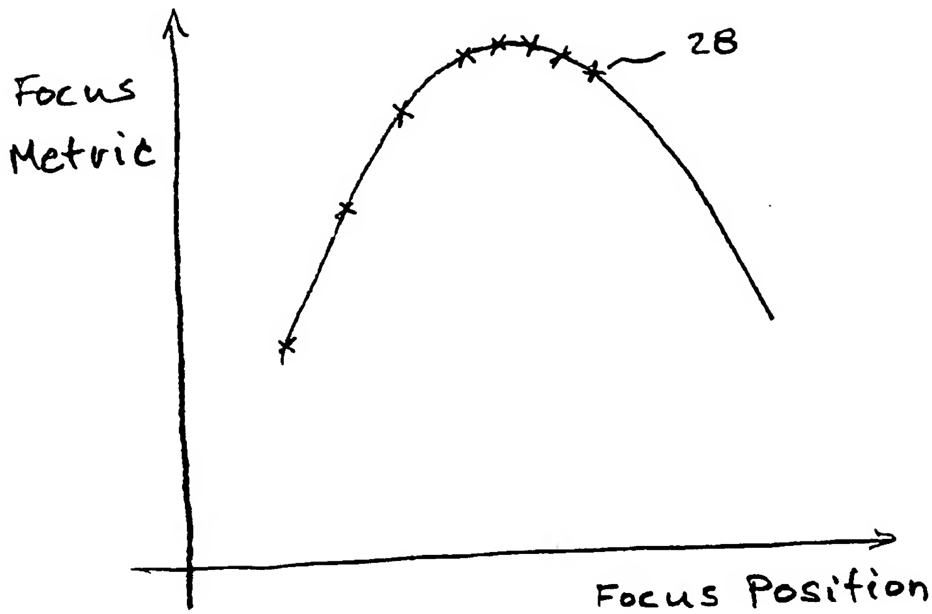


FIG. 3

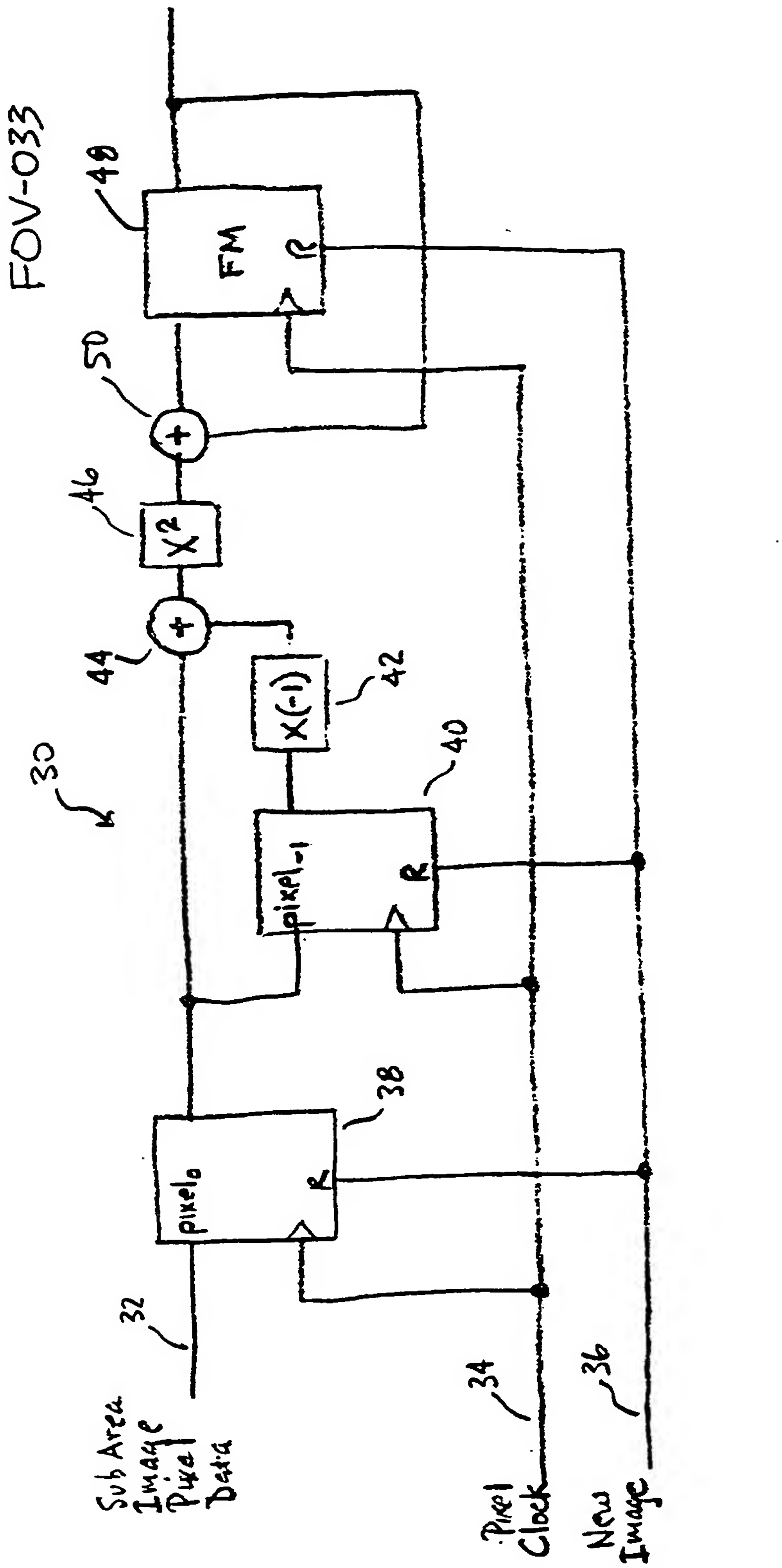

FOV-033
48
FM
R
50
46
X^2
44
42
X(-1)
30
40
$pixel_{-1}$
R
38
$pixel_0$
R
32
34
36
Sub Area Image Pixel Data
Pixel Clock
New Image

FIG. 4

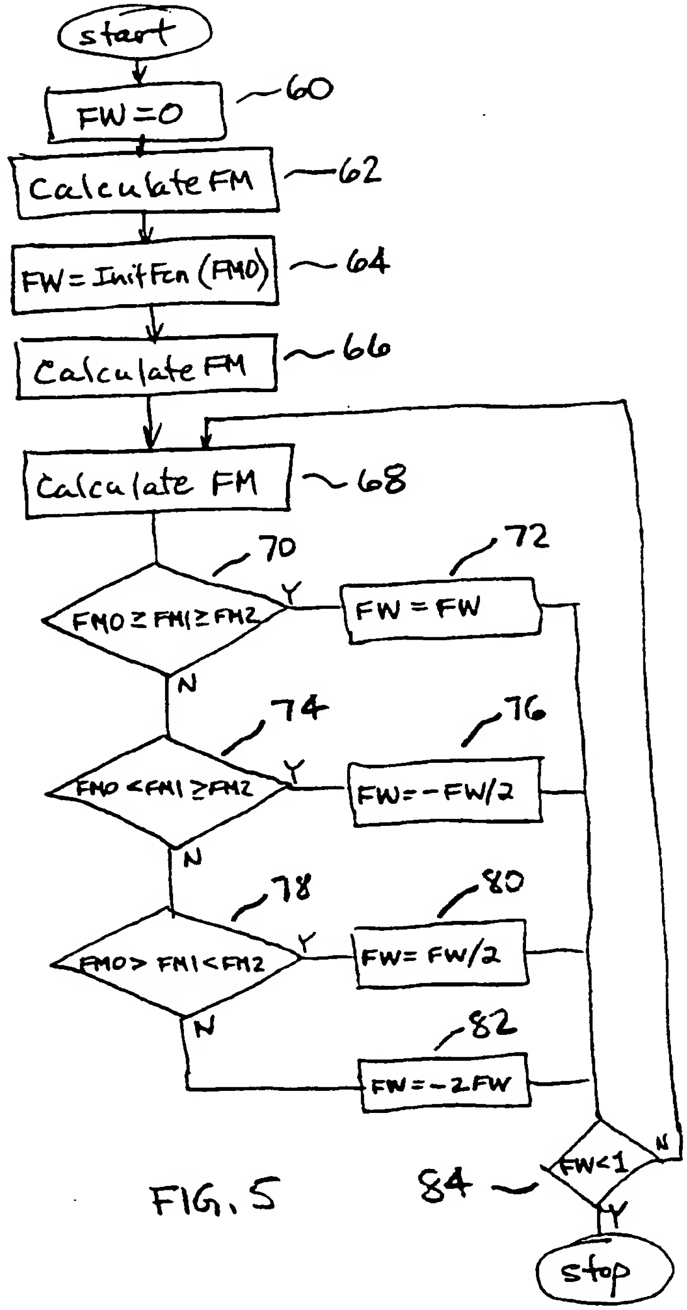


FIG. 5

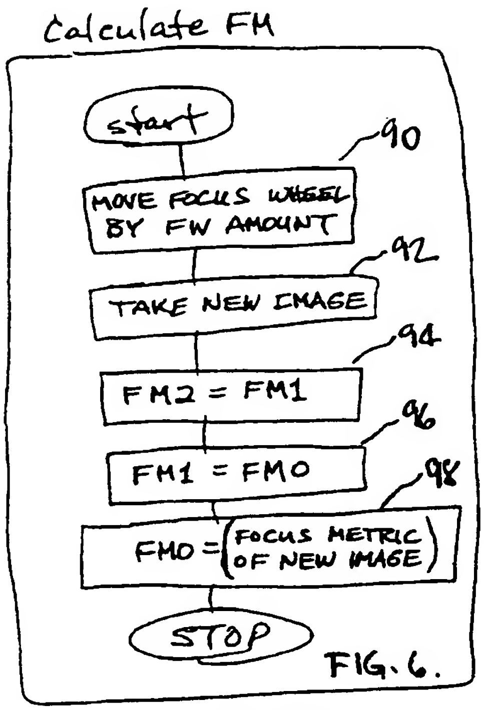


FIG. 6.

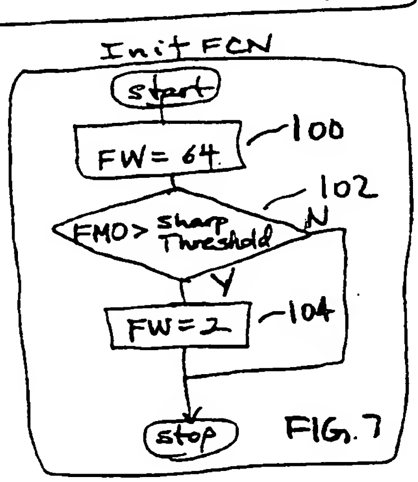
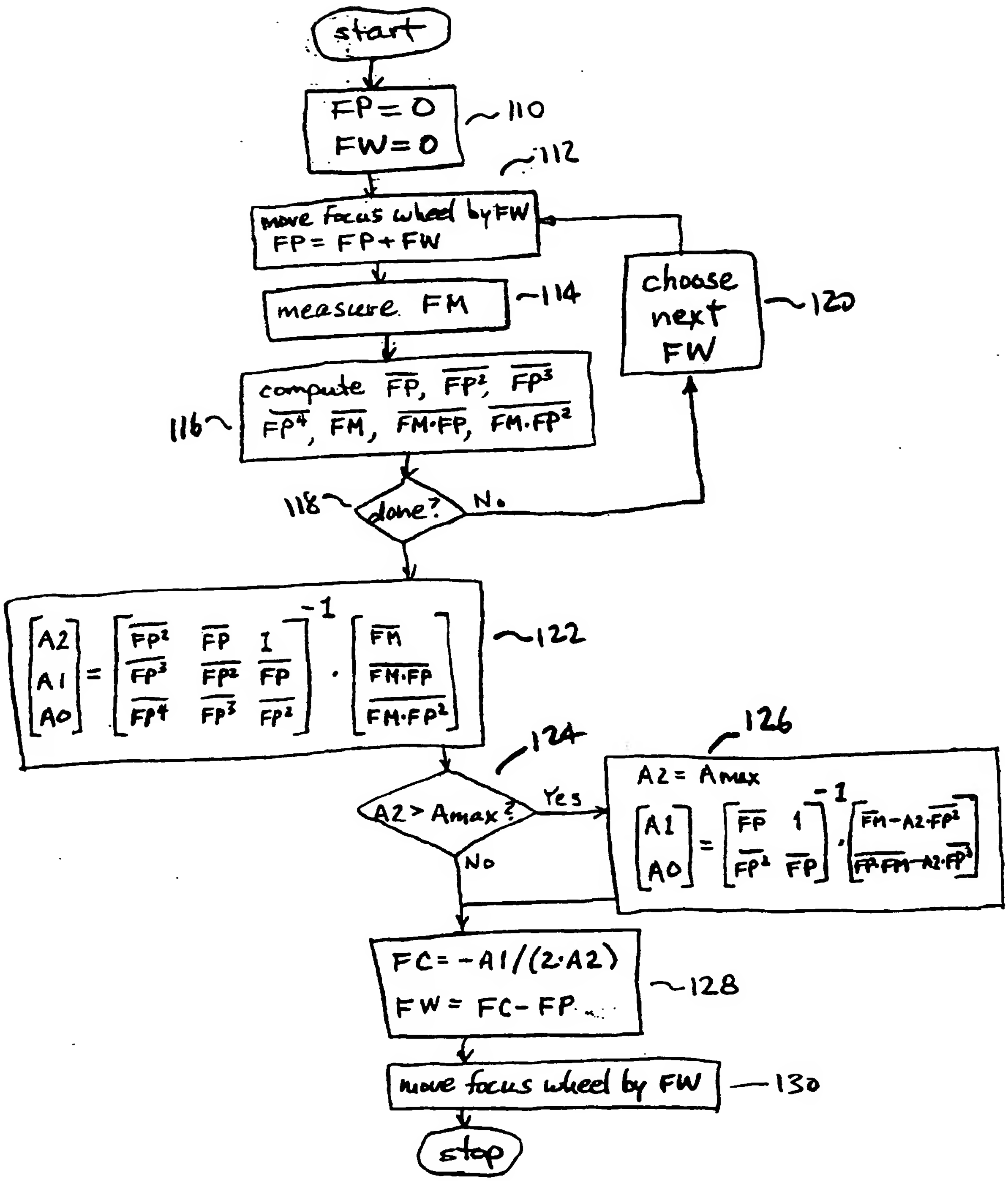


FIG. 7


start
FP=0
FW=0
110
112
move focus wheel by FW
FP = FP+FW
measure FM
114
compute FP, FP², FP³
FP⁴, FM, FM·FP, FM·FP²
116
118
done?
No
choose next FW
120
[A2; A1; A0] = [FP² FP 1; FP³ FP² FP; FP⁴ FP³ FP²]⁻¹ · [FM; FM·FP; FM·FP²]
122
124
A2 > Amax?
Yes
No
126
A2 = Amax
[A1; A0] = [FP 1; FP² FP]⁻¹ · [FM−A2·FP²; FP·FM−A2·FP³]
FC = −A1/(2·A2)
FW = FC−FP
128
move focus wheel by FW
130
stop

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/07988

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04N5/232

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 838 370 A (KAJI TOSHIO) 17 November 1998 (1998-11-17) column 2, line 1 - line 22 column 3, line 58 -column 7, line 53	1-7
X	WO 95 15054 A (SINAR AG SCHAFFHAUSEN ;KOCH HANS CARL (CH); GFELLER KARL (CH)) 1 June 1995 (1995-06-01) page 9, line 16 -page 15, line 2 page 21, line 4 - line 15	1,2,4-6
A	US 5 349 415 A (NISHIDA YOSHIHIRO) 20 September 1994 (1994-09-20) column 4, line 63 -column 5, line 46 column 8, line 56 -column 9, line 21	1-7

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 July 2000	24/07/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Wentzel, J

1

Inter onal Application No
PCT/US 00/07988

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 113 392 A (SHARP KK) 18 July 1984 (1984-07-18) page 1, line 6 -page 2, line 16	1,4
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A	US 4 814 889 A (COVEY ROBERT L) 21 March 1989 (1989-03-21)	

1

INTERNATIONAL SEARCH REPORT

...ormation on patent family members

Inter nal Application No
PCT/US 00/07988

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
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			JP	8506464	T	09-07-1996
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			EP	0454354	A	30-10-1991
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			DE	3372835	D	03-09-1987
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EP 0720360	A	03-07-1996	US	5668597	A	16-09-1997
			DE	69515833	D	27-04-2000
			JP	8223465	A	30-08-1996
US 4814889	A	21-03-1989	NONE			

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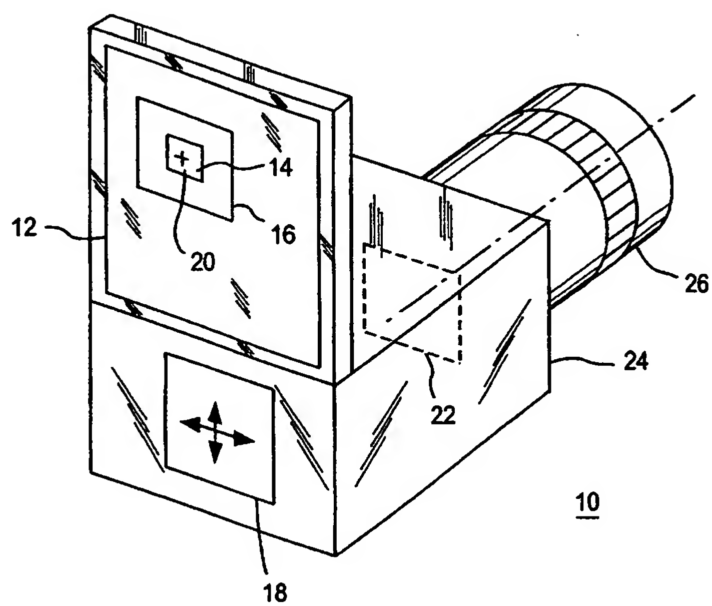
(54) Title: TARGETABLE AUTOFOCUS SYSTEM



(57) Abstract: A digital camera comprises a light-tight housing. At least one solid-state array image sensor is disposed in the housing. A lens is optically coupled to the solid-state array image sensor through the housing. A viewing screen is coupled to the solid-state array image sensor for viewing an image sensed by the solid-state array image sensor. A user-operated pointing device is used to select a point anywhere on the image. Circuitry associated with the solid state array image sensor is responsive to the pointing device for presenting on the viewing screen an area associated with the point on the image, the area being magnified and having higher resolution with respect to the remainder of the image.

WO 00/72584 A1

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

TARGETABLE AUTOFOCUS SYSTEM

1. Field of the Invention

The present invention relates to digital imaging devices and to digital cameras. More particularly, the present invention relates to a targetable autofocus system and to a digital camera employing a targetable autofocus system.

2. The Prior Art

Autofocus systems are known in the prior art, particularly as represented in consumer "point and shoot" cameras, and also in professional level single-lens reflex cameras. These systems operate by splitting the image in a small active area in the center of the field of view into two sub-images. These two sub-images are then passed through separate optical paths and compared to produce an electrical error signal that is an odd function of the defocus distance, as is well known by those of ordinary skill in the art. This error signal is used to operate the focus motor of the lens, thereby bringing the sub-image into focus. The direction that the focus motor is to be driven is known from the sign of the odd error signal.

Looking through the view finder of such a camera, the photographer aims the box delineating the focus area at the part of the image that he or she desires to be in focus, depresses the shutter release button half way, moves the camera to achieve the desired framing for the shot, and then depresses the shutter release button all the way, thereby actually exposing the image. Some of the more advanced cameras have several sub-image areas that are switched between by the camera using some algorithm. Some of the Canon cameras even attempt to track the eye position of the photographer to determine which of the predetermined sub-images to use for a particular exposure.

Digital cameras have simply copied this style of auto-focus system, providing no advantage over their film counterpart. It is an object of the present invention to provide an auto-focus system for a digital camera that uses the signals from the same digital image sensor that is used to capture the image to operate the focus motor, without the requirement of a separate optical system or sensor. It is a second object of the present invention to provide an auto-focus system for a digital camera that operates on a sub-image area selectable by the user rather than fixed by the manufacturer.

BRIEF DESCRIPTION OF THE INVENTION

BRIEF DESCRIPTION OF THE DRAWING FIGURES

FIG. 1 is a schematic diagram of a front view of a viewfinder display for an electronic camera.

FIG. 2 is an image showing the appearance of the display employing the present invention.

FIG. 3 is a plot of focus metric as a function of lens focus setting.

FIG. 4 is a block diagram of a circuit for computing individual data points of the focus metric shown in FIG. 3.

FIG. 5 is a flow diagram is used to illustrate a method for performing autofocus according to the present invention.

FIG. 6 is a flow diagram of a process that may be used for calculating a new focus metric for use in the method of FIG. 5.

FIG. 7 is a flow diagram illustrating a process for setting an initial focus wheel increment for use in the method of FIG. 5.

FIG. 8 is a flow diagram illustrating a method for computing a fit to a parabolic error curve, and focusing at the estimated best position.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Persons of ordinary skill in the art will realize that the following description of the present invention is illustrative only and not in any way limiting. Other embodiments of the invention will readily suggest themselves to such skilled persons having the benefit of this disclosure.

The present invention can be better understood with reference to FIG. 1, which shows, in schematic form, a view of a viewfinder display for an electronic camera 10. The main window 12 is used to display the entire image that is within the field of the electronic imaging array used to capture the image. Persons of ordinary skill in the art will understand that any high-quality imaging array will have much higher resolution than can be fully displayed on an electronic display small enough to fit on a portable camera, and hence only a small fraction of the actual pixels in the sensor array are addressed in order to produce the video stream used to form the image displayed in window 12. For example, a high-quality imaging system can be formed using three 2,000 by 2,000 pixel sensor chips attached to a color-separating prism as described in co-pending application serial No. 09/302,565, filed April 30, 1999, entitled "COLOR SEPARATION PRISMS HAVING SOLID-STATE IMAGERS MOUNTED THEREON AND CAMERA EMPLOYING SAME" Attorney's Docket No. FOV-031, assigned to the same assignee as the present invention and expressly incorporated by reference herein.

A typical liquid-crystal viewfinder display has 512 by 512 pixels. To display a video image from the sensor array on the viewfinder screen, every fourth row of the sensor array is addressed, and every fourth pixel is outputted from each addressed row. In the present example where every fourth pixel is used, a 500 by 500 pixel displayed image is created, containing one 16th of the total number of pixels of the full 2,000 by 2,000 sensor array. This subsampling of the sensor array may be accomplished by addressing circuitry integrated on the sensor chip, as disclosed, for example, in co-pending application serial No. 09/120,491, filed July 21, 1998, entitled "IMAGE SCANNING CIRCUITRY WITH ROW AND COLUMN ADDRESSING FOR USE IN ELECTRONIC CAMERAS" and assigned to the same assignee as the present invention. This prior application is expressly incorporated by reference herein. The advantage of creating the viewfinder image by on-chip subsampling of the sensor array is that the number of pixels to be read off the chip is reduced by a large factor (16 in the example just cited), thereby allowing a faster frame rate viewfinder to be implemented within the bandwidth limit of the readout system.

Referring again to FIG. 1, a selectable sub-area 14 of the image in the main window 12 is defined by the user by, for example, using a pointing device 18 like a touchpad,

joystick, or the like to move and position a cursor-like target, cross-hairs, or other indicator (indicated at reference numeral 20) centered therein at a region of interest in an image. Sub-area 14 is selected by the user as an area of the image that is of particular interest, such as the eye of a person of which a photograph is to be taken. Because each photographic composition is unique, it is important that the region of interest be movable by the photographer. The present invention provides this feature, which is not available in the prior art.

In operation, the sub-area 14 is scanned out at full resolution, also using the addressing circuitry integrated on the sensor chip, as disclosed in co-pending application serial No. 09/120,491. The pointing device 18 is centered by the user on a point of interest anywhere in the image. As will be readily understood by persons of ordinary skill in the art having the benefit of this disclosure and that of co-pending application serial No. 120,491, the starting row and column addresses for sub-area 14 are easily derived from the row and column addresses of the position of the pointing device 14 defining the center of sub-area 14. The starting row address of the sub-area 14 is derived by subtracting half of the length (in rows) of the sub-area 14 from the row address of the position of the pointing device. The starting column address of the sub-area 14 is derived by subtracting half of the width (in columns) of the sub-area 14 from the column address of the position of the pointing device.

The result is a full-resolution image that, when displayed at viewfinder screen resolution, is larger than area 14. Using the numbers from the example system disclosed herein, the area required to display sub-area 14 on the screen at full resolution would be 4 times larger in each dimension, or 16 times larger in area, than the area defined as sub-area 14.

According to a presently preferred embodiment of the invention, the full-resolution version of area 14 is displayed as magnified area 16, centered on area 14, and replaces the corresponding image region on the original display. The visual impression created by this superposition is that of a magnifying glass or "loupe", expanding the portion of the image of sub-area 14 beneath it. The appearance of the display according to the present invention is shown on the image in FIG. 2. Magnification techniques have been used for material such as text or images stored in computer memory, but have not been used for magnifying a user-

selectable sub-area of the live viewfinder image in a portable electronic camera as in the present invention. The ability to scan the high-resolution image sensors in two different modes interleaved in time is crucial to achieving the magnified sub-image without compromising performance. In the presently preferred embodiment of the present invention, this interleaving is achieved by storing the start and stop addresses and the addressing increment for each of the modes in control registers on the chip, as disclosed in co-pending application serial No. 120,491, filed July 2, 1998, and toggling between them to retrieve the data in area 12 and sub-area 16.

The viewfinder may be mounted on camera 10 at a convenient location. As will be appreciated by persons of ordinary skill in the art, camera 10 focuses an image onto at least one imager array 22 located in light-tight enclosure 24 via lens 26. Lens 26 is a variable focus lens and is equipped with a focus motor to move the lens elements as is known in the art.

A second aspect of the present invention is to utilize the data displayed in sub-area 16 to drive the focus motor of the camera lens 26, thereby achieving an autofocus capability specifically within the region of interest selected by the photographer. Because sub-area 16 of the image has a small amount of data compared with the entire image in main window 12, it can be refreshed at a much higher rate.

A high-resolution electronic imaging system located in the image plane of the camera lens does not provide an odd-error signal as required by prior-art camera auto-focus systems. There has been work on using even-error metrics of focus quality from imaging arrays to operate a focus system, as described, for example, in T. Delbruck, ``A chip that focuses an image on itself", in Analog VLSI implementation of neural systems, C. Mead and M. Ismail, Eds., chapter 7, pp. 171-188. Kluwer Academic Publishers, Boston, 1989, Proceedings of a workshop on Analog Integrated Neural Systems. According to the present invention, an even-error metric of image quality is developed from the image itself, for example by taking the sum of the squares of first-difference of adjacent pixels over the area. A plot of this kind of focus metric as a function of lens focus setting is shown in FIG. 3. One of the individual data points for the focus metric is indicated at reference numeral 28.

According to the present invention as illustrated in FIG. 3, the measured function is fitted to a parabola, and the lens focus setting returned to the position of computed maximum (best focus). Although this kind of computation has been performed before, it has not been possible to accomplish in the context of a portable, high-resolution camera because it requires many images to be scanned out, each at a different lens focus setting. The time required to scan out a high-resolution image is of the order of one second, and thus scanning out many images could not result in a real-time auto-focus system. However, scanning out user-selected sub-image 16 at high resolution according to the present invention can be done in a small fraction of a second. The plurality of sub-images, each at a different lens focus setting, that is required for computing the point of best focus can be done within a second. Thus the present invention makes possible a real-time autofocus system that optimizes the focus in the area of the image selected by the user.

Referring now to FIG. 4, a block diagram is presented of a circuit 30 for performing an illustrative computation that determines individual data points of the focus metric shown in FIG. 3. The circuit 30 is driven by three lines. First, the pixel data stream is presented on line 32. The pixel clock is presented on pixel clock line 34. A New Image signal is presented on New Image line 36. A pixel0 register 38 is driven by the pixel data stream on line 32 and the pixel clock on line 34. Pixel0 register 38 is first cleared by New Image signal on line 36. The next clock pulse on pixel clock line 34 clocks the value of the current pixel (pixel0) into pixel0 register 38.

The second clock pulse on pixel clock line 34 clocks the value of the new current pixel (pixel0) into pixel0 register 38 and also clocks the most recent old current pixel (pixel-1) into pixel-1 register 40. Pixel-1 register 40 has also been cleared by New Image signal on line 36. The pixel-1 output of pixel-1 register 40 is multiplied by (-1) in multiplier 42 to change its sign and is then subtracted from the value of the current pixel0 in adder 44. The subtraction result is squared in unit 46.

The output of unit 46 is added to the output of focus-metric register 48 in adder 50. Persons of ordinary skill in the art will appreciate that focus-metric register 48 has also been cleared by the New Image signal on line 36. Therefore, focus-metric register 48 will contain

the value zero after the first pixel clock pulse following assertion of the New Image signal on line 36. It will contain a value equal to the square of the value in pixel0 register 38 after the second pixel clock pulse following assertion of the New Image signal on line 36. It will contain a value equal to the sum of the squares of the first two pixel values only after the third pixel clock pulse following assertion of the New Image signal on line 36. After all of the pixel values for a sub-image have been clocked in, the output of focus-metric register 48 represents the sharpness of the sub-image. After the value has been read by some other register, the New Image signal is asserted on line 36 to reset all of the registers 38, 40 and 48 in circuit 30 and the next sub-image may be read into circuit 30. Circuit 30 assumes that each pixel value clocked in by the pixel clock is from a pixel adjacent to the previous pixel value clocked in and should not perform calculations on non-adjacent pixels, i.e., the last pixel on a line and the first pixel on the next line.

Persons of ordinary skill in the art will appreciate that circuit 30 can run in either of the horizontal and vertical lines of the sub-image, or that two such circuits 30 may be employed, one each on selected lines in the horizontal and vertical directions. Such skilled persons will also appreciate that the algorithm implemented by circuit 30 is not the only means for determining the focus of an image based upon pixel values. Another embodiment could filter the sub-image more through the use of an edge detect algorithm. Only pixels near the most defined edge could be run through such a system.

Referring now to FIG. 5, a flow diagram is used to describe an illustrative method for performing autofocus according to the present invention. The method of FIG. 5 searches for maximum image sharpness by obtaining focus metric values and moving the camera focus mechanism (referred to herein as the "focus wheel") to change lens focus based upon the three previous focus metric values. The system of FIG. 5 always tries to move the lens to achieve higher focus metric values based upon the focus metric history.

In the method illustrated in FIG. 5, the focus wheel increment value (FW) controlling how much the focus mechanism of the lens will be changed is initially set to zero at step 60. A first focus metric FM0 is then calculated (using, for example, circuit 30 of FIG. 4) at step 62. At step 64, the initial focus wheel increment value FW is set depending on whether or

not the focus metric FM0 is greater than a sharpness threshold. The FW increment set in step 64 is explained in greater detail in FIG. 7.

Next, at step 66, a new focus metric FM0 is calculated by circuit 30 using the focus wheel increment value FW. At step 68, a new focus metric FM0 is again calculated by circuit 30 using the current focus wheel increment value FW. At step 70, the new focus metric calculated at step 68 is compared to the most recent focus metric FM1 (from step 66) and the next most recent focus metric FM2 (from step 62) to test whether the condition FM0≥FM1≥FM2 is true. Step 66 was repeated at step 68 so that there are non-zero values for FM1 and FM2 the first time that the test in step 70 is performed. If the condition FM0≥FM1≥FM2 is true, then the current focus setting resulting in focus metric FM0 is at least as good as the most recent focus setting that resulted in focus metric FM1 and the most recent focus setting is at least as good as the next-most-recent focus setting that resulted in focus metric FM2. This indicates that the focus wheel FW is incrementing in a direction towards optimum focus. Step 72 is then performed to maintain the focus wheel increment at its current value FW.

If FM0≥FM1≥FM2 is not true at step 70, the new focus metric calculated at step 68 is compared to the most recent focus metric FM1 and the next-most-recent focus metric FM2 at step 74 to test whether the condition FM0<FM1≥FM2 is true. If the condition FM0<FM1≥FM2 is true, then the current focus setting is worse than the most recent focus setting that resulted in focus metric FM1 and the most recent focus setting that resulted in focus metric FM1 was not worse than the next-previous focus setting that resulted in focus metric FM2. This means that the current focus setting FM0 has moved past the optimum focus setting. In this case, step 76 is then performed to set the focus wheel increment value FW to a new value equal to -FW/2 in order to reverse the focus wheel direction back towards the optimum focus point. The magnitude of the increment is set to an amount equal to half that of the previous increment in order to avoid overshooting the optimum focus point

If FM0<FM1≥FM2 is not true, the new focus metric calculated at step 68 is compared to the most recent focus metric FM1 and the next-most-recent focus metric FM2 at step 78 to test whether the condition FM0>FM1<FM2 is true. If the condition FM0>FM1<FM2 is true,

then the current focus setting is better than the previous focus setting that resulted in focus metric FM1 but the most recent focus setting that resulted in focus metric FM1 is not as good as the next-most-recent focus setting that resulted in focus metric FM2. This condition is typically true when a new focus metric has been calculated using the focus wheel increment value FW = -FW/2 following the condition FM0<FM1>FM2 and the current focus setting that resulted in focus metric FM0 has moved back towards the optimum focus setting. In this case, step 80 is then performed to set the focus wheel increment value FW to the value FW/2 to increment the focus wheel further towards the optimum point by half the previous increment to avoid overshoot.

If FM0>FM1<FM2 is not true, then the current focus setting is not as good as the most recent focus setting that resulted in the focus metric FM1 and the most recent focus setting that resulted in the focus metric FM1 was not as good as the next -most-recent focus setting that resulted in the focus metric FM2. This means that the initial focus setting FM2 was past the optimum focus setting and the focus settings FM1 and FM0 continue to move away from the optimum focus setting. In this case, step 82 is then performed to set the focus wheel increment FW to the value -2FW to reverse the focus wheel direction back towards the optimum point by a larger increment. This will reverse the sign (direction of travel) of the focus wheel increment value FW and bring the focus setting back to the setting that resulted in the focus metric FM2. As will be understood from an examination of FIG. 6, the focus wheel increment value will increment in a direction towards optimum focus the next time a focus metric is calculated.

After performance of any of steps 72, 76, 80, or 82, step 84 is performed to test whether the current focus wheel increment value FW is less than 1. If FW<1, then the optical system is close enough to an in-focus condition and the process stops. If not, the process returns to step 68 to calculate a new focus metric FM0.

Referring now to FIG. 6, a flow diagram is used to illustrate a method for calculating a new focus metric for use in the method of FIG. 5. First, at step 90, the focus wheel is moved by the increment FW. Next, at step 92, a new image is captured by the imager using the new focus setting. In steps 94, 96, and 98, respectively, the old FM2 value is replaced by

the old FM1 value, the old FM1 value is replaced by the old FM0 value, and the old FM0 value is replaced by the FM value calculated for the newly-acquired image. As previously noted with respect to steps 66 and 68 of FIG. 5, these two steps are performed in order to provide initial non-zero values for FM1 and FM2.

Referring now to FIG. 7, an illustrative method is shown for selecting an initial focus wheel increment value FW to use in the process of FIG. 5. First, at step 100, FW is set equal to 64. Then at step 102, a determination is made whether the first FM0 calculated at step 62 is greater than a sharpness threshold. If not, the FW initialization ends with the value FW set to 64. If, however, the sharpness of the image FM0 was greater than the threshold, step 104 is performed to set the value FW to 2. Performance of this process strikes a balance between taking too much time to focus if the initial lens setting was significantly out of focus and using too large an FW increment and overshooting the optimal focus setting if the initial lens setting was close to optimum focus. By using the values 64 and 2, both of which are powers of 2, repeated performances of combinations of steps 76 and 80 will eventually reduce the value of FW to 0.5 to make the FW<1 condition of step 84 true to end the focus search algorithm of FIG. 5.

The method described in FIG. 5 is one of many possible methods of converging on a focus setting near the optimum. Ideally, it runs to completion, and stops after reducing the focus wheel increment (FW) to less than the minimum resolvable step of the lens motor (less than 1 in FIG. 5). If, however, the measurements of the focus metric (FM) are subject to noise, as would typically be the case, or if the subject is constantly in motion while running this method, then it is possible that the FW value will be successively halved and doubled many times as the method attempts to track the point of best focus. In this case, the method may not stop, or may not converge soon enough before the photographer snaps a picture. For such cases, it would be advantageous to fit a parabolic error curve to the recent FM values in order to compute a final FW increment that will drive the focus motor to an estimated best setting.

Whether the method of FIG. 5 is used, or some other method of sampling possible focus positions is used, it is therefore useful to be able to compute a final increment FW to drive the focus from its current setting to an estimated best focus setting.

Referring now to FIG. 8, a flow diagram illustrates a method for computing a fit to a parabolic error curve, and focusing at the estimated best position. In a first step 110 FP and FW are set to zero. FP is a focus position value and FW is the focus wheel increment value. At step 112, the lens focus wheel is moved by an amount FW and the position FP is updated to reflect the new position by setting FP = FP + FW. At step 114, the focus metric FM is measured. Next, at step 116, the averages of the quantities FP, FP2, FP^3, FP^4, FM, FM*FP, and FM*FP^2 are calculated. At step 118, it is determined whether all data has been taken. If not, at step 120 a new FW is chosen. The steps "choose Next FW" and "done?" may be defined to correspond to the steps in the method of FIG. 5 or as like steps in some other focus tracking method. For example, the "done?" test may be answered by user input, such as letting go of an auto-focus button or pressing a shutter release, or it may be answered by the convergence of a tracking method such as that described with reference to FIG. 5.

If the decision in the "done?" step 120 is yes, the method proceeds to determine an estimate of a best focus position by fitting a parabolic error function to the measurements from the settings. Many methods of parameter estimation are known; for simplicity, the well-known method of least-squares curve fitting to find a parabola (a quadratic, the simplest error function that has even symmetry about its optimum) that best fits the last N data values is used, where N is a chosen number of points, typically 5 to 10. In order to compute the fit of the parabola, the focus positions, which are not explicit in the method of FIG. 5, need to be obtained. To do so, either the absolute positions can be read from an encoder attached to the lens motor, or if such a device is not available, the method can simply start with an arbitrary position of zero and accumulate the increments FW to keep track of relative focus position FP, as shown in the method of FIG. 8.

As is well known in the art, the computation of the best fit to a quadratic error function can be done incrementally, since it depends only on average values of the independent variable FP, the dependent variable FM, and products and powers thereof

(means of FP, FP^2, FP^3, FP^4, FM, FM*FP, FM*FP^2). These averages can be computed as running averages of N points, or as exponentially weighted averages of points. Therefore, a focus-tracking method can stop and compute a final step FW at any time with little work.

According to the embodiment of the method shown in FIG. 8, a set of focus position (FP) values and focus metric (FM) values is used in steps 122 124, and 126 to compute the coefficients (A2, A1, and A0) of a best fitting quadratic function:

$$FM(FP) \sim= A2*FP^2 + A1*FP + A0$$

Equivalently, a parabola may be parameterized in terms of its center:

$$FM(FP) \sim= A2*(FP - FC)^2 + B0$$

where the parameter FC represents the focus-center or peak of the parabola in the focus-position dimension, and is given in step 128 by solving for the point where the first parameterization has zero slope:

$$FC = -A1/(2*A2)$$

The parameters A0 and B0 are not relevant to locating the best focus position but it is easiest to include them in the matrix solution to the least squares problem.

A further potential problem, in the case of a noisy focus metric, or in the case where there is little structure in the subject to focus upon, or in the case where the search has started near the optimum and moved only in very small increments, is that the estimated parablic error function could be nearly flat across the region sampled, or even inverted, such that the position of the best focus could be severely mis-estimated. A solution to this problem is to do a constrained least-squares fit in which the curvature parameter A2 is constrained to be more negative than (less than) some negative limiting value Amax, which will force the parabola to have a narrow enough peak and the estimated center value FC to be within or near the sampled positions FP even when there is little or no information in the FM data. If

Fig. 8, a fit to best values of A1 and A0 is computed with A2 fixed at Amax if the first computed value of A2 is not sufficiently negative.

Once the value of FC is determined in step 128, the lens can be returned to the position of best focus by setting FW = FC - FP as also shown at step 128 , where FP is the most recent focus position, and then incrementing the focus motor position by this final increment FW in step 130.

While embodiments and applications of this invention have been shown and described, it would be apparent to those skilled in the art that many more modifications than mentioned above are possible without departing from the inventive concepts herein. The invention, therefore, is not to be restricted except in the spirit of the appended claims.

What is claimed is:

1. A digital camera comprising:

a light-tight housing;

at least one solid-state array image sensor disposed in said housing;

an adjustable-focus lens having a focussing mechanism, said lens optically coupled to said solid-state array image sensor through said housing;

a viewing screen coupled to said solid-state array image sensor for viewing an image sensed by said solid-state array image sensor;

a user-operated pointing device that selects a point anywhere on said image;

circuitry associated with said solid-state array image sensor and responsive to said pointing device for presenting on said viewing screen a group of pixels representing an area associated with said point on said image, said area being magnified and having higher resolution with respect to the remainder of said image.

2. The digital camera of claim 1, further including:

circuitry for processing pixels representing said area associated with said point on said image to derive focus data; and

focussing means, coupled to said circuitry, for driving said focussing mechanism in response to said focus data from said circuitry such that said image is focussed on said imaging array within a selected tolerance.

3. The digital camera of claim 2 wherein said focus data defines a focus parabola and wherein said selected tolerance is a focus-center peak of said focus parabola.

4. In a digital camera having a light-tight housing, at least one solid-state array image sensor disposed in the housing, an adjustable-focus lens having a focussing mechanism, the lens being optically coupled to the solid-state array image sensor through the housing, a viewing screen coupled to the solid-state array image sensor for viewing an image sensed by the solid-state array image sensor, and a user-operated poining device that selects a focus point on said viewing screen, a method for focussing an image presented on the viewing screen comprising:

directing an image from the variable-focus lens onto said at least one solid-state array image sensor;

displaying said image on the viewing screen;

sensing an output signal from the user-operated pointing device identifying a point on said viewing screen;

defining an area associated with said point on said viewing screen;

reading a group of pixels from the at least one solid-state array image sensor that represent a magnified and higher-resolution view of a portion of said image associated with said point; and

displaying said group of pixels in said focus area on said viewing screen.

5. The method of claim 4 further including performing an autofocus operation on said group of pixels that adjusts the sharpness of said image from said variable-focus lens onto said at least one solid-state array image sensor.

6. The method of claim 5 wherein performing the autofocus operation comprises:

processing said group of pixels representing said area associated with said point on said image to derive focus data; and

driving the focussing mechanism of the lens in response to said focus data such that said image is focussed on said imaging array within a selected tolerance.

7. The method of claim 6 wherein processing said focus data comprises processing said focus data to define a focus parabola and wherein said selected tolerance is a focus-center peak of said focus parabola.

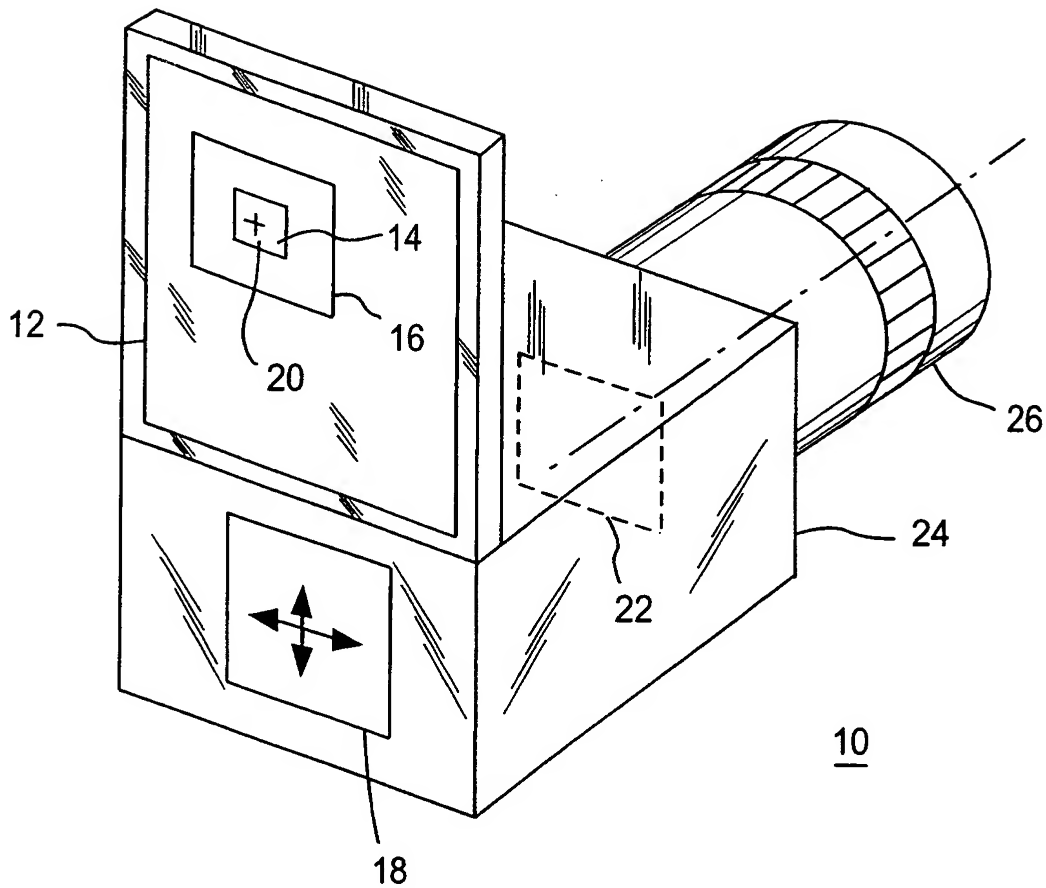


Fig. 1

Fig. 2

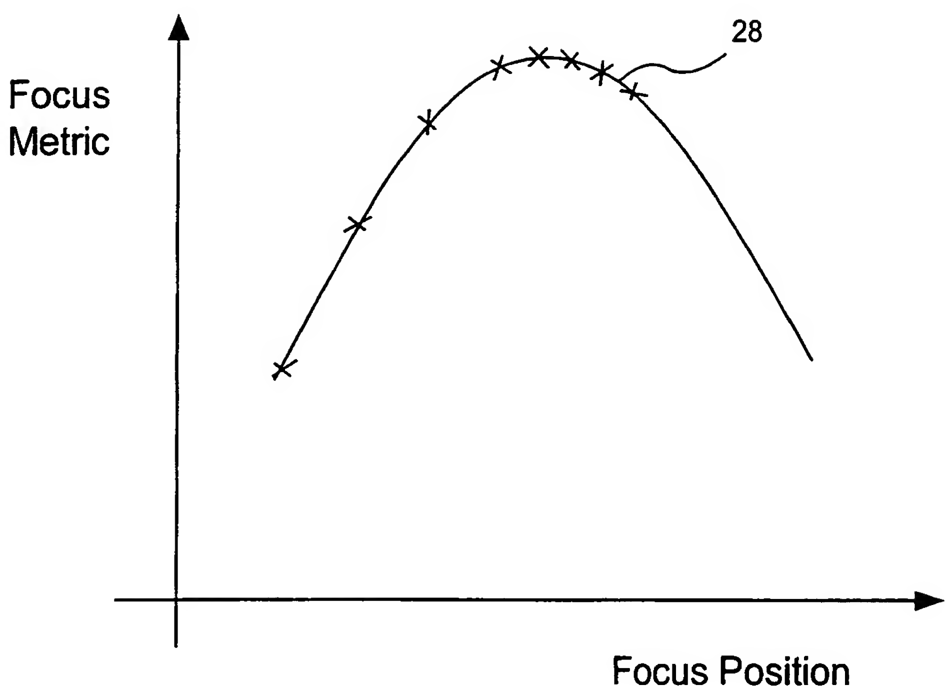
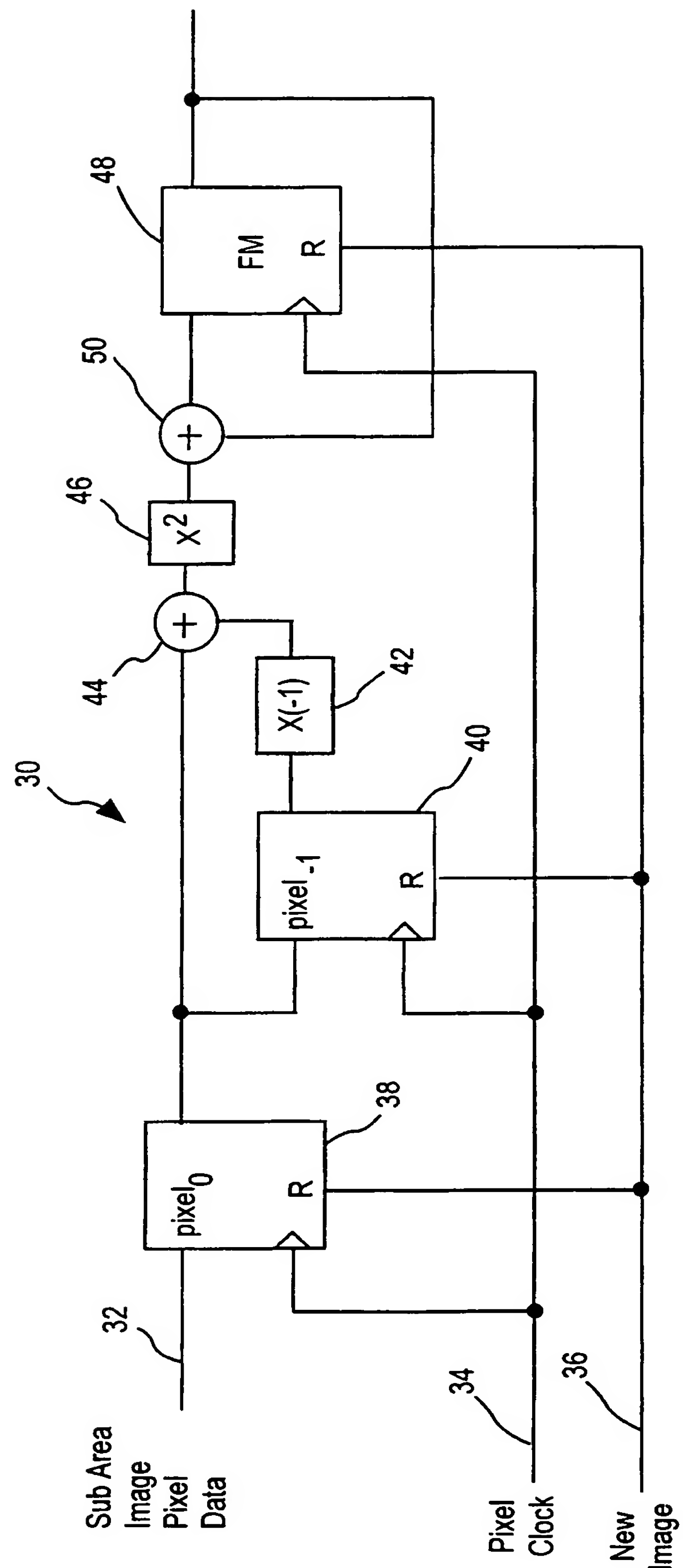


Fig. 3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Pixel Clock
New Image
pixel0
pixel-1
R
FM
X(-1)
X2
30
32
34
36
38
40
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44
46
48
50

Fig. 4

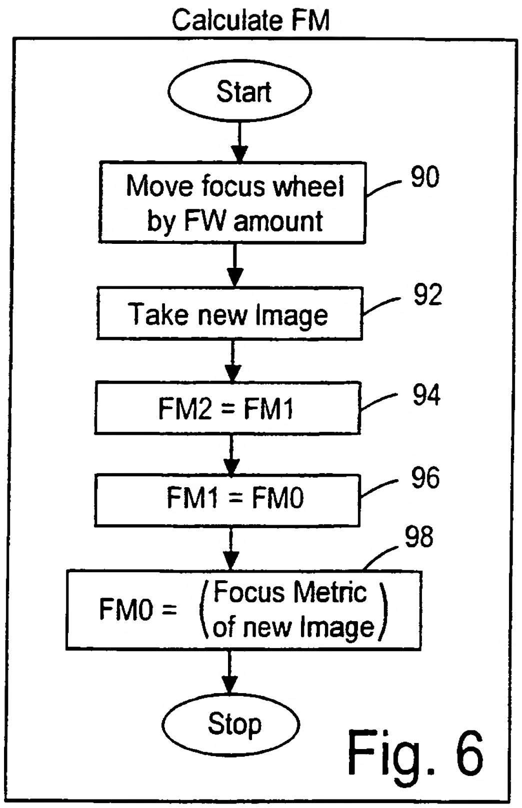

Fig. 6

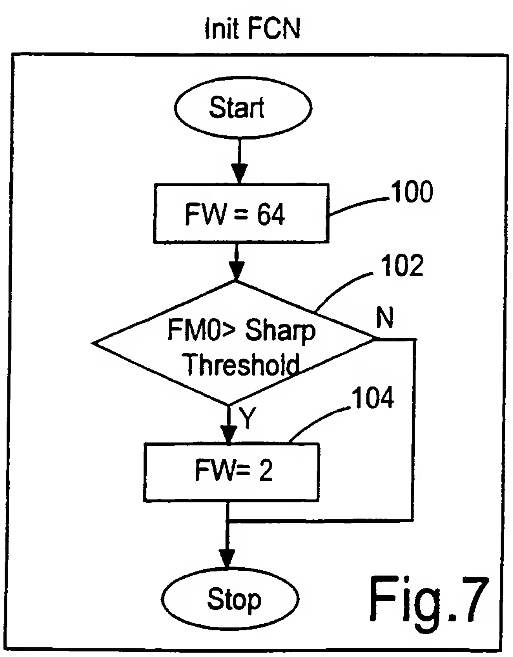

Fig.7

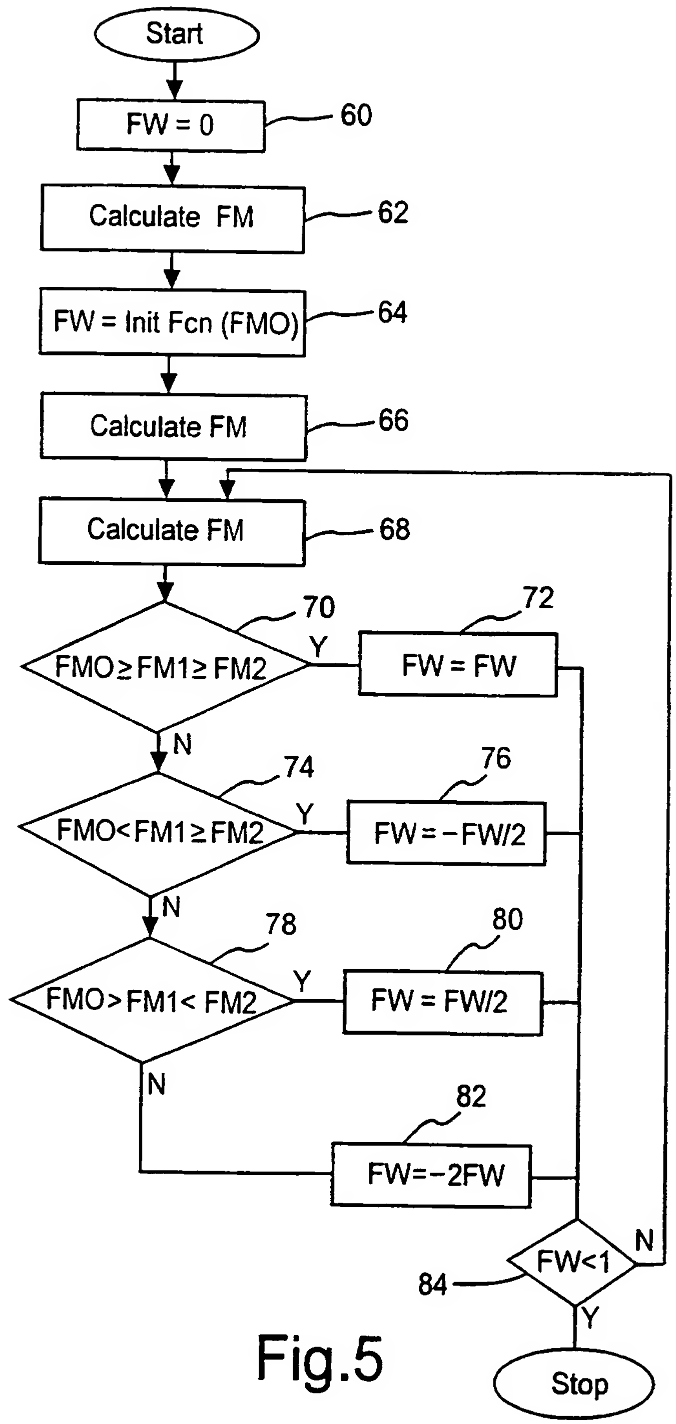

Fig.5

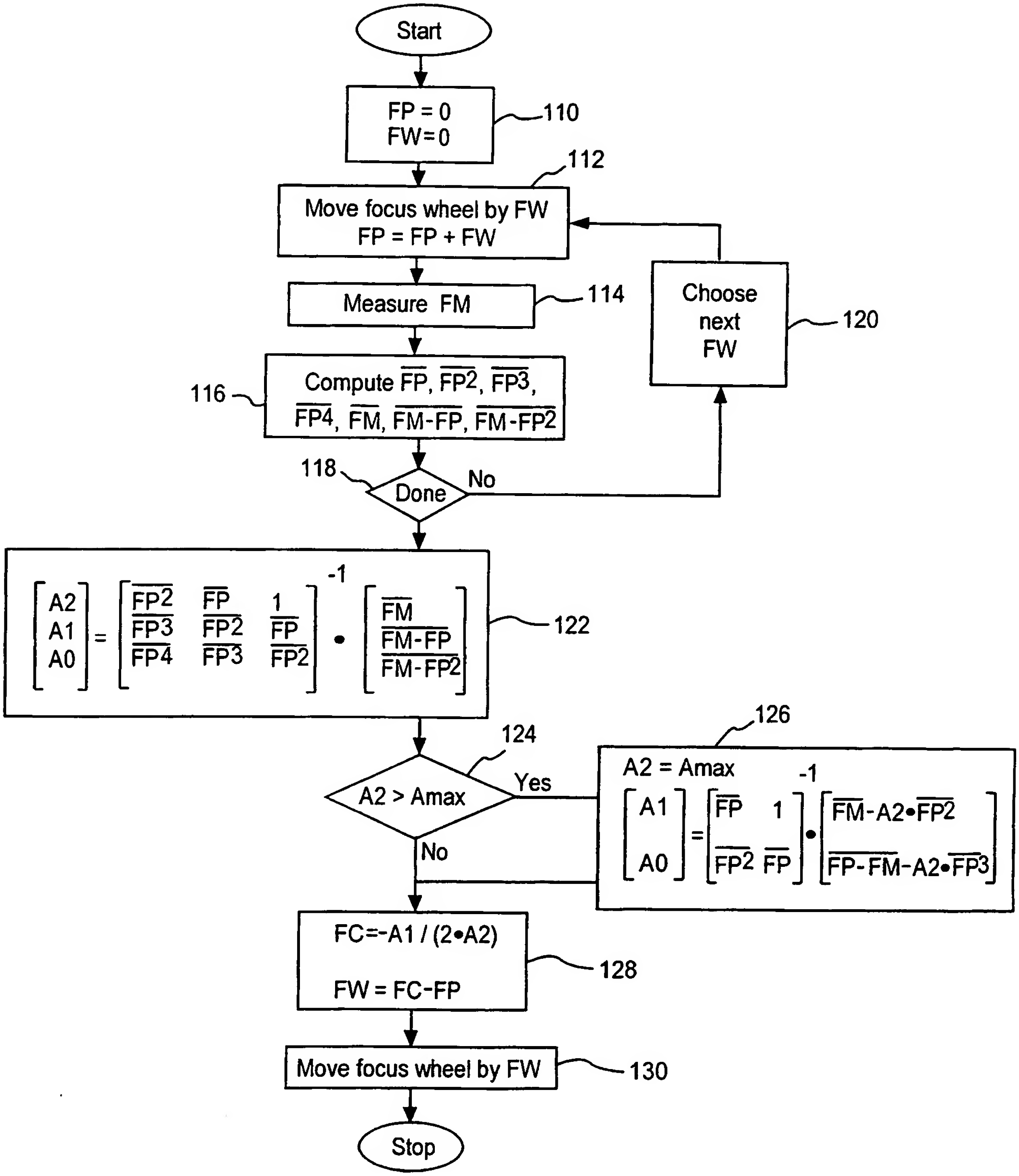
Start
FP = 0
FW=0
110
112
Move focus wheel by FW
FP = FP + FW
Measure FM
114
Choose next FW
120
116
Compute $\overline{FP}$, $\overline{FP2}$, $\overline{FP3}$, $\overline{FP4}$, $\overline{FM}$, $\overline{FM\text{-}FP}$, $\overline{FM\text{-}FP2}$
118
Done
No
$\begin{bmatrix} A2 \\ A1 \\ A0 \end{bmatrix} = \begin{bmatrix} \overline{FP2} & \overline{FP} & 1 \\ \overline{FP3} & \overline{FP2} & \overline{FP} \\ \overline{FP4} & \overline{FP3} & \overline{FP2} \end{bmatrix}^{-1} \bullet \begin{bmatrix} \overline{FM} \\ \overline{FM\text{-}FP} \\ \overline{FM\text{-}FP2} \end{bmatrix}$
122
124
126
A2 > Amax
Yes
No
A2 = Amax
$\begin{bmatrix} A1 \\ A0 \end{bmatrix} = \begin{bmatrix} \overline{FP} & 1 \\ \overline{FP2} & \overline{FP} \end{bmatrix}^{-1} \bullet \begin{bmatrix} \overline{FM} - A2 \bullet \overline{FP2} \\ \overline{FP\text{-}FM} - A2 \bullet \overline{FP3} \end{bmatrix}$
FC=-A1 / (2•A2)
FW = FC-FP
128
Move focus wheel by FW
130
Stop

Fig. 8

INTERNATIONAL SEARCH REPORT

Inter nal Application No
PCT/US 00/07988

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04N5/232

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 838 370 A (KAJI TOSHIO) 17 November 1998 (1998-11-17) column 2, line 1 - line 22 column 3, line 58 -column 7, line 53 ---	1-7
X	WO 95 15054 A (SINAR AG SCHAFFHAUSEN ;KOCH HANS CARL (CH); GFELLER KARL (CH)) 1 June 1995 (1995-06-01) page 9, line 16 -page 15, line 2 page 21, line 4 - line 15 ---	1,2,4-6
A	US 5 349 415 A (NISHIDA YOSHIHIRO) 20 September 1994 (1994-09-20) column 4, line 63 -column 5, line 46 column 8, line 56 -column 9, line 21 --- -/--	1-7

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 July 2000	24/07/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Wentzel, J

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Form PCT/ISA/210 (second sheet) (July 1992)

Inte[illegible]onal Application No
PCT/US 00/07988

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
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A	US 4 814 889 A (COVEY ROBERT L) 21 March 1989 (1989-03-21) -----	

1

INTERNATIONAL SEARCH REPORT

...ormation on patent family members

Inter— ·nal Application No
PCT/US 00/07988

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		DE 69515833 D	27-04-2000
		JP 8223465 A	30-08-1996
US 4814889 A	21-03-1989	NONE	

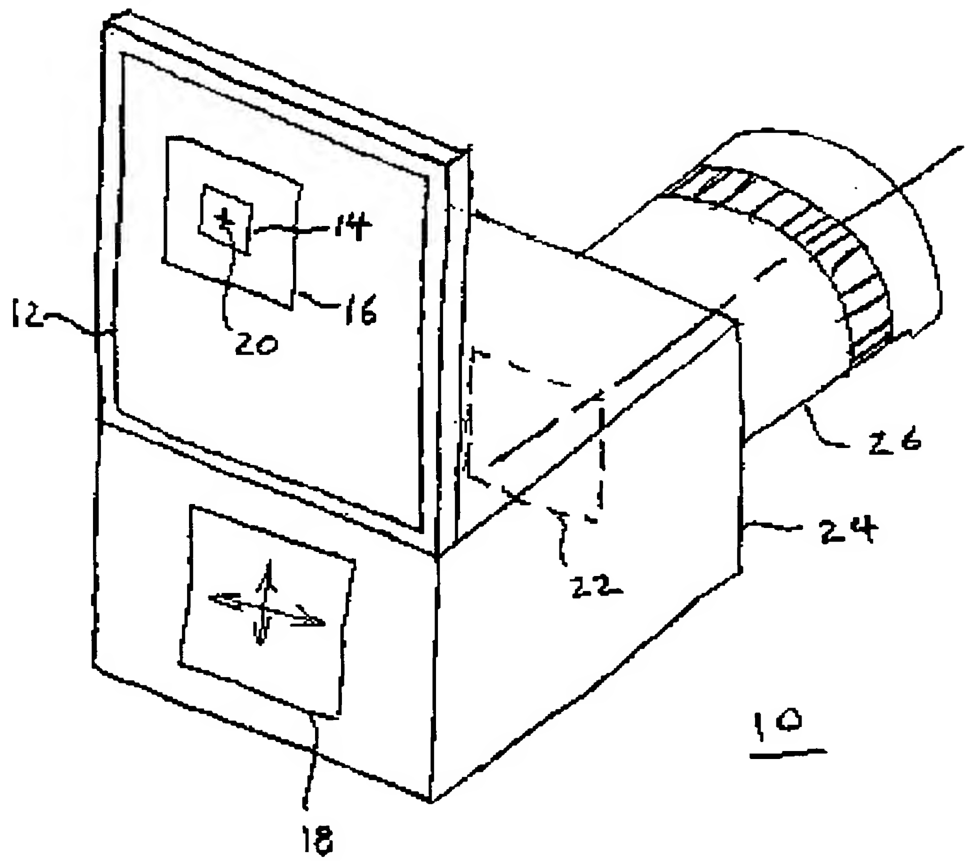


FIG. 1

G. 2

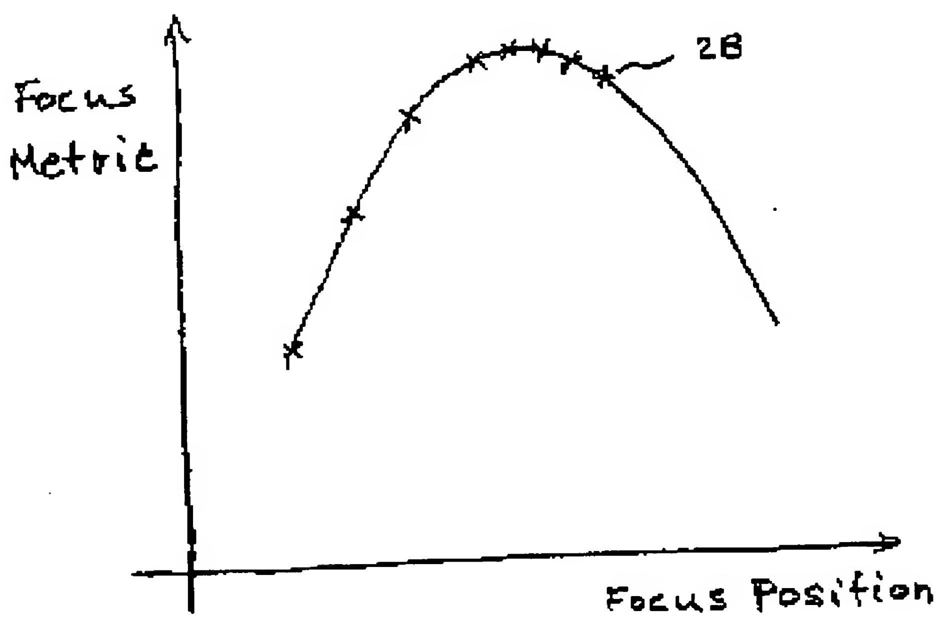


FIG. 3

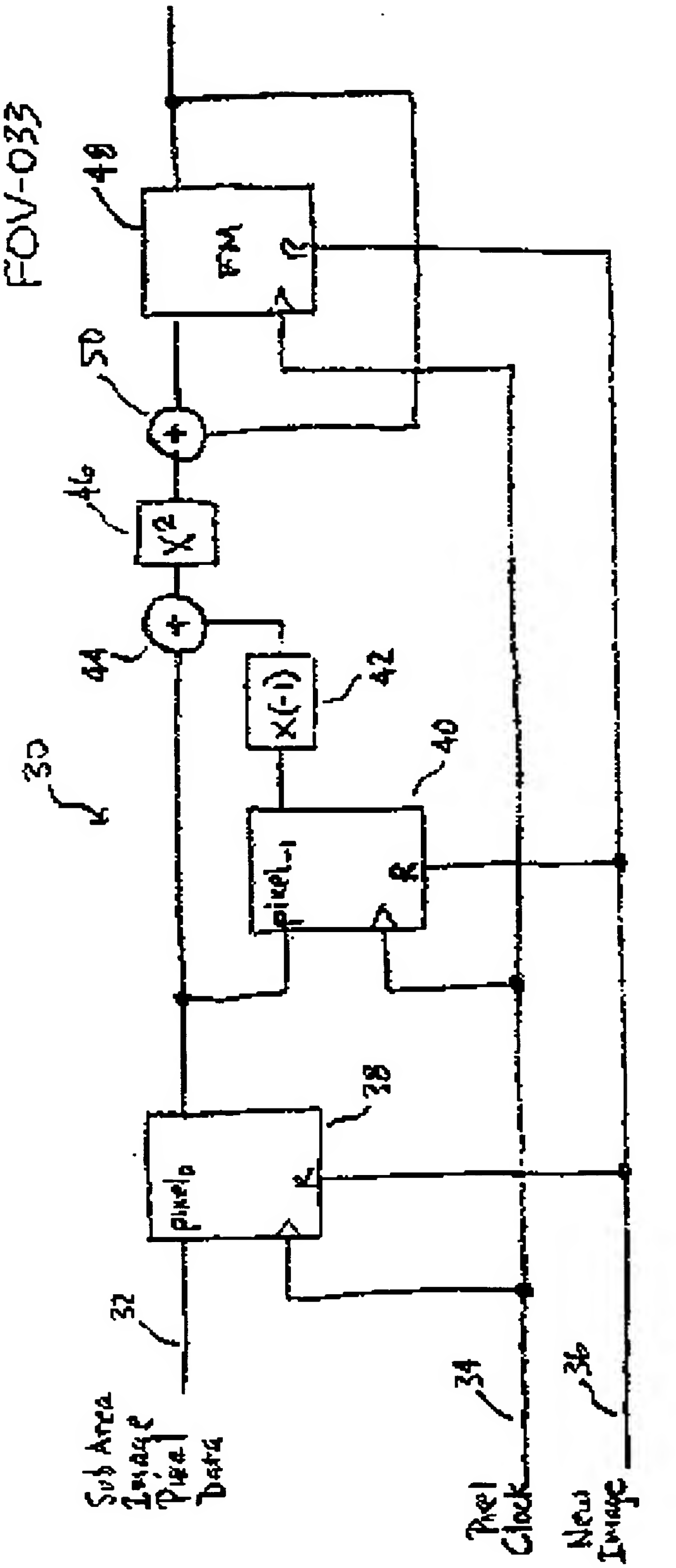

FOV-033
30
48
FM
R
50
46
X²
44
X(-1)
42
40
pixel-1
R
28
pixel0
R
32
Sub Area Image Pixel Data
34
Pixel Clock
36
New Image

FIG. 4

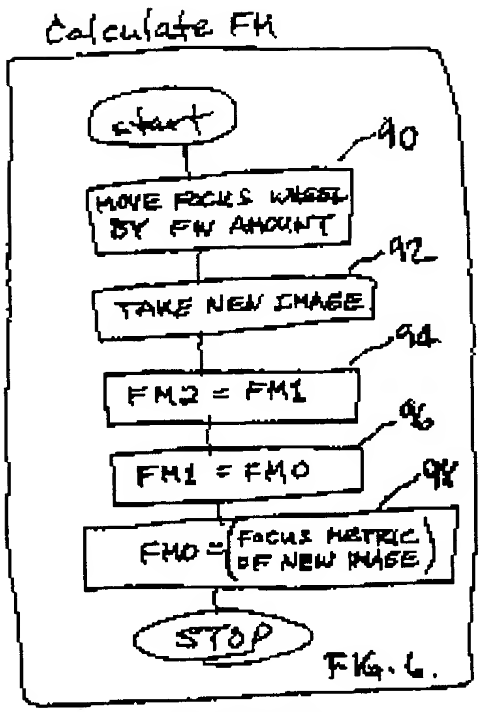


FIG. 6.

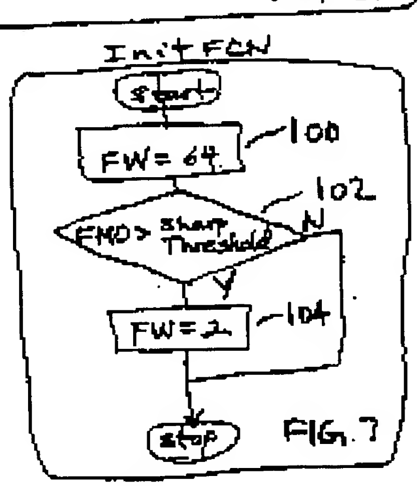


FIG. 7

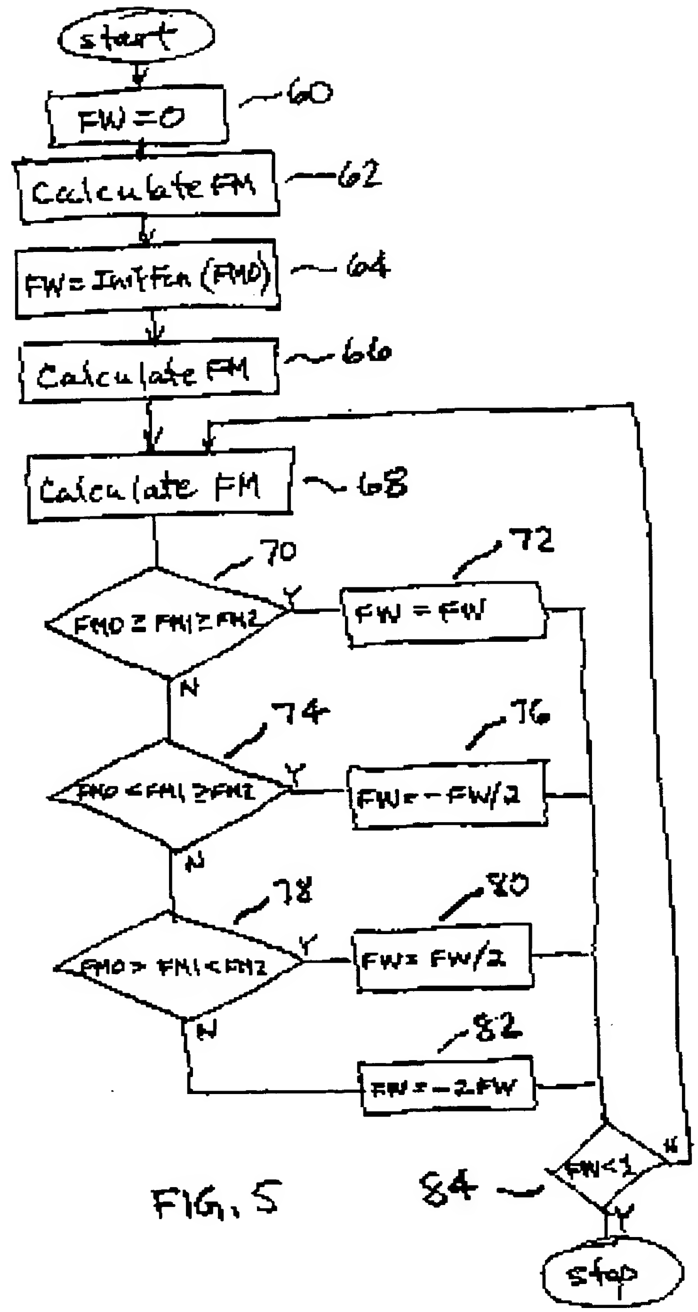
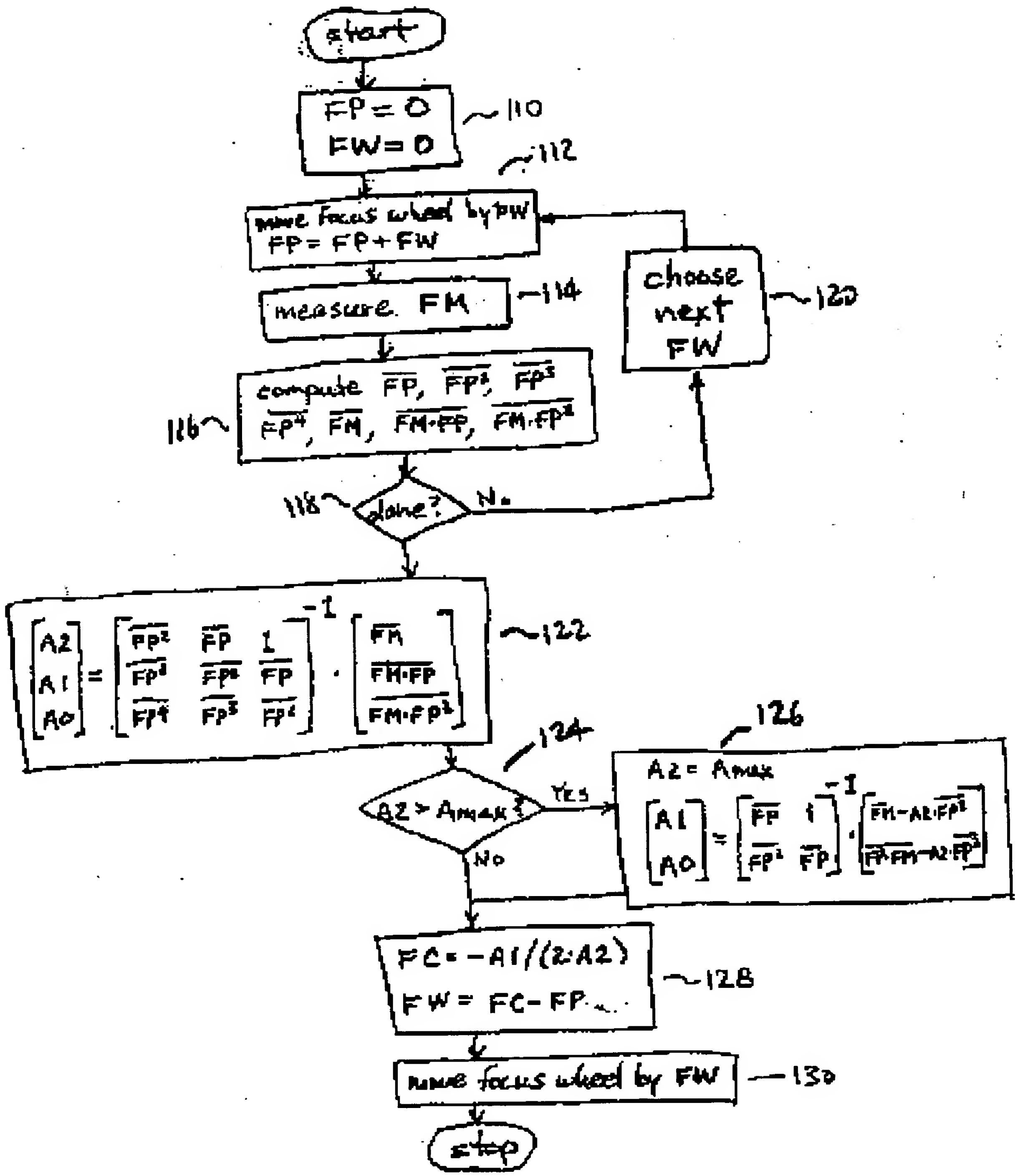


FIG. 5


start
FP = 0
FW = 0
110
112
move focus wheel by FW
FP = FP + FW
measure FM
114
compute FP, FP², FP³
FP⁴, FM, FM·FP, FM·FP²
116
118
done?
No
choose next FW
120
122
124
A2 > Amax?
Yes
No
126
A2 = Amax
128
FC = −A1/(2·A2)
FW = FC − FP
move focus wheel by FW
130
stop